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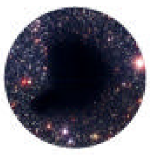
Hole in the universe



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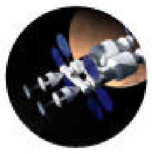

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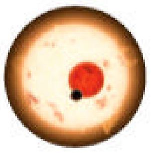

Out team of experts answer your questions about the universe 74

There's a hole in the universe. Granted, it's not a physical hole that leads us to a place that's outside the cosmos - it's a void where there isn't a great deal going on. And that's because there's supposedly nothing there: no matter, no stars, no galaxies, no black holes. Zilch.

So what's going on inside it, and how did it get there? That's one discussion I had with **All About Space**'s Art Editor, Jonathan Wells, and the answer is quite illuminating to say the least. Turn to page 14 for everything you need to know (and the current research) into one of the weirdest places in the universe.

Also in this issue, we've created a quick bluffer's guide to understanding the fundamental properties of nature at a subatomic level, the ambitious plan to stop the heating up of our planet, why Mars is wobbling, how the Moon is getting more water and plenty more to keep you entertained. As usual, we're also giving away three eBooks to read at your leisure.

This marks our second issue where we feature augmented reality (AR) - we hope you love the experience, and if this is the first time that you've been introduced to it, we hope you enjoy interacting with the magazine in a whole new way. See you next issue!

GEMMA LAVENDER

EDITOR-IN-CHIEF

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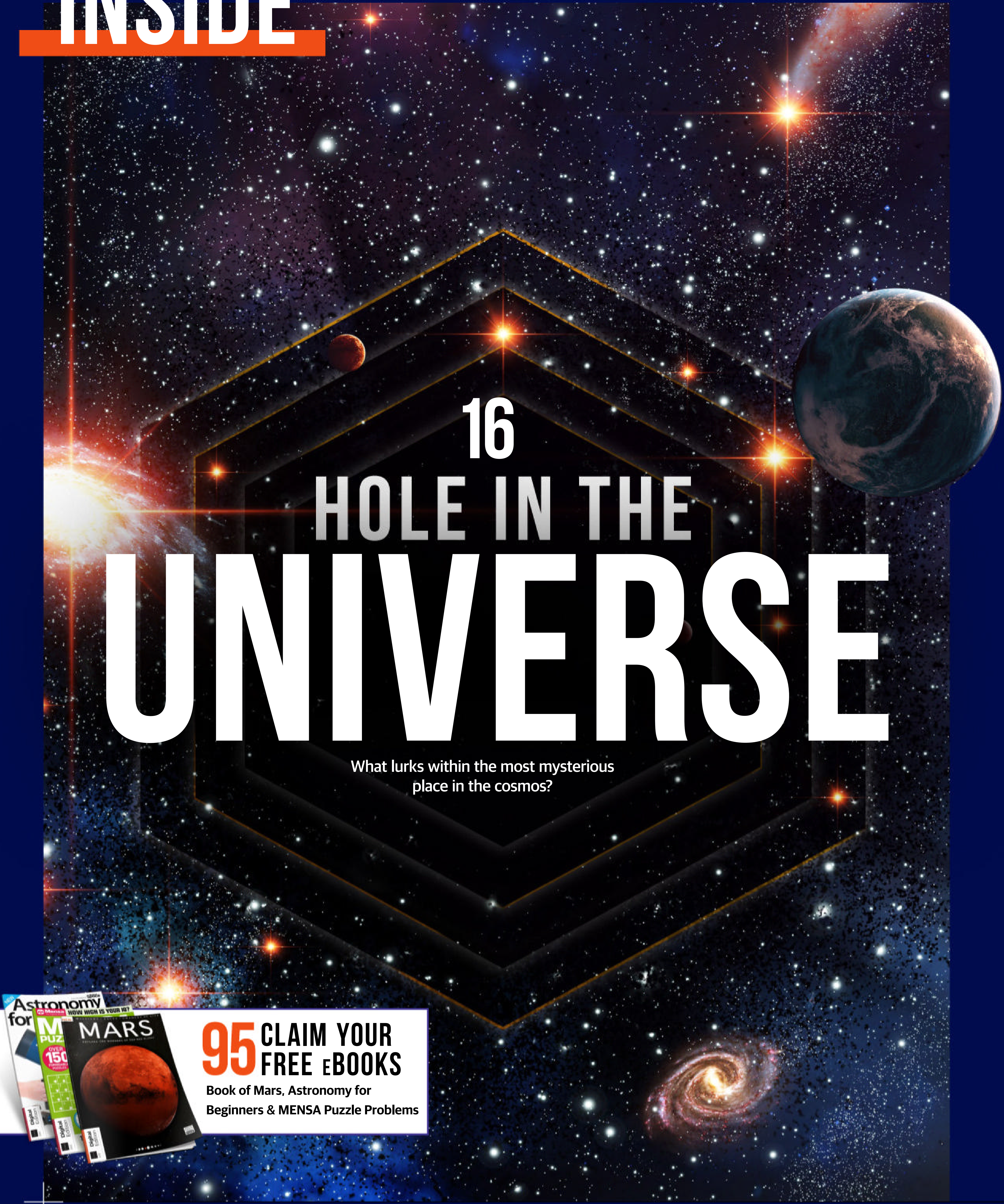

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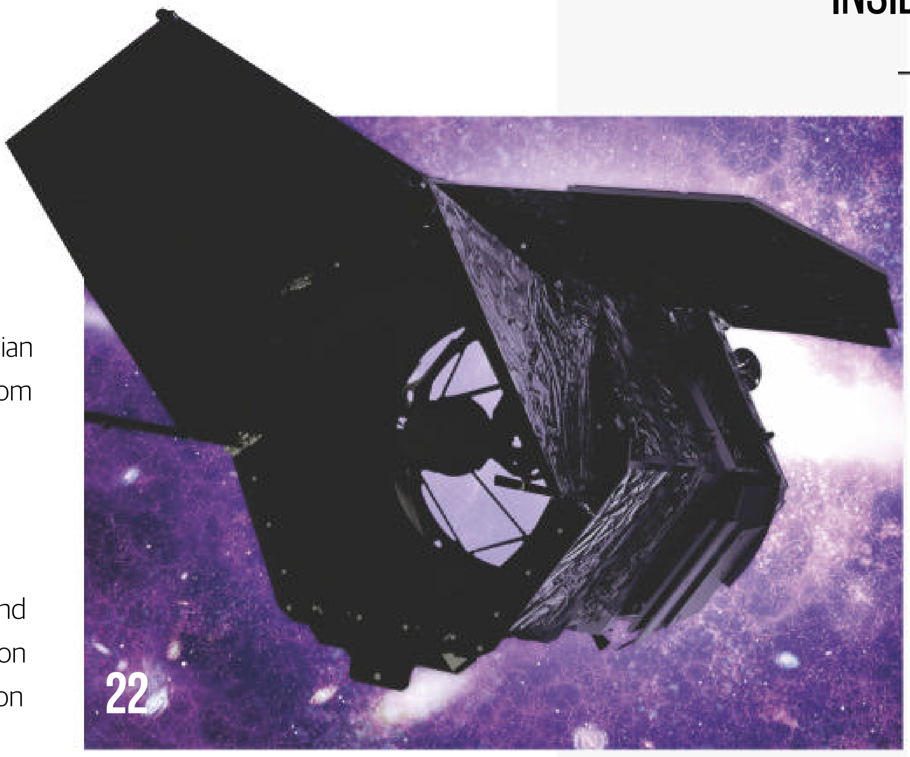
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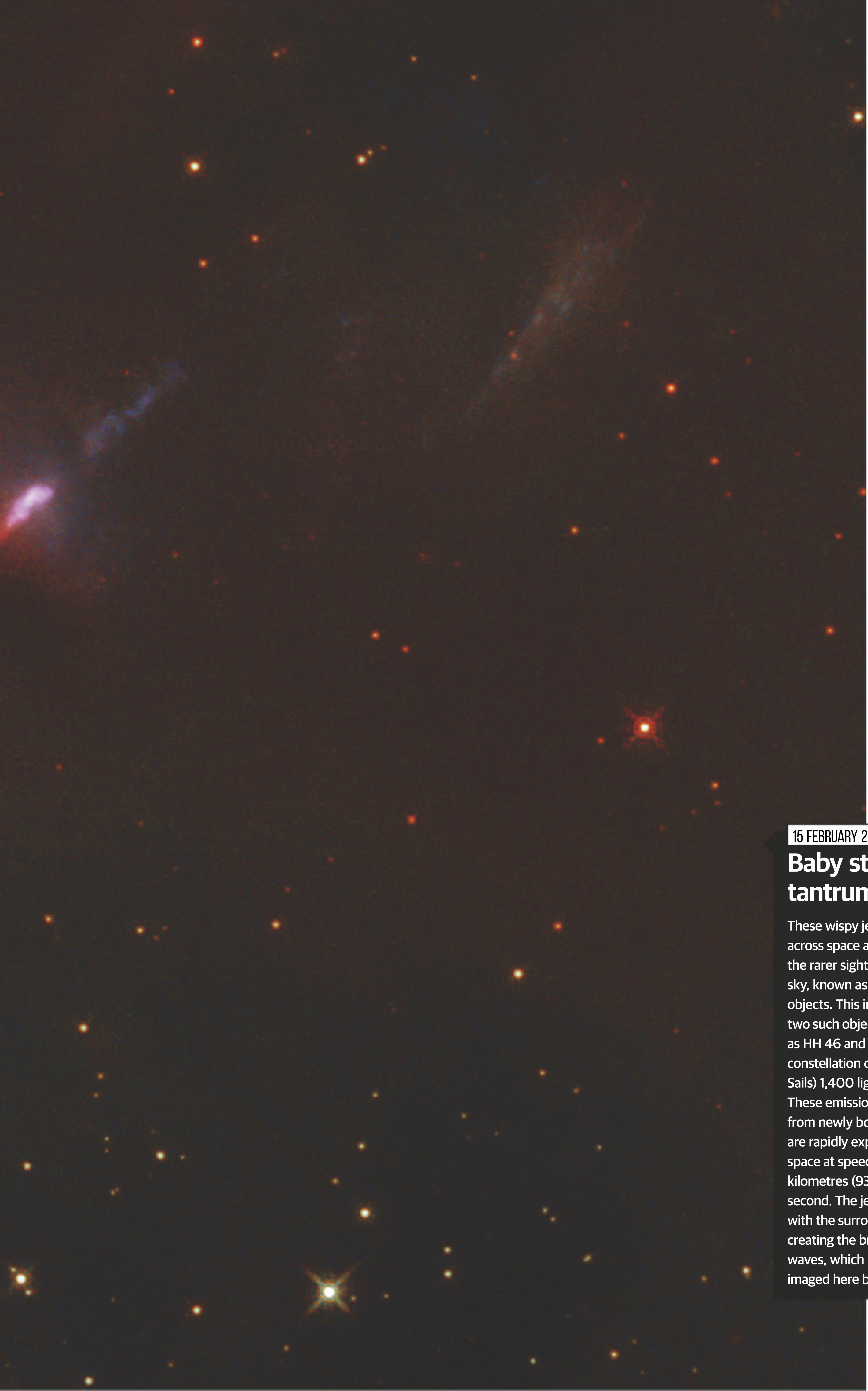


15 FEBRUARY 2021

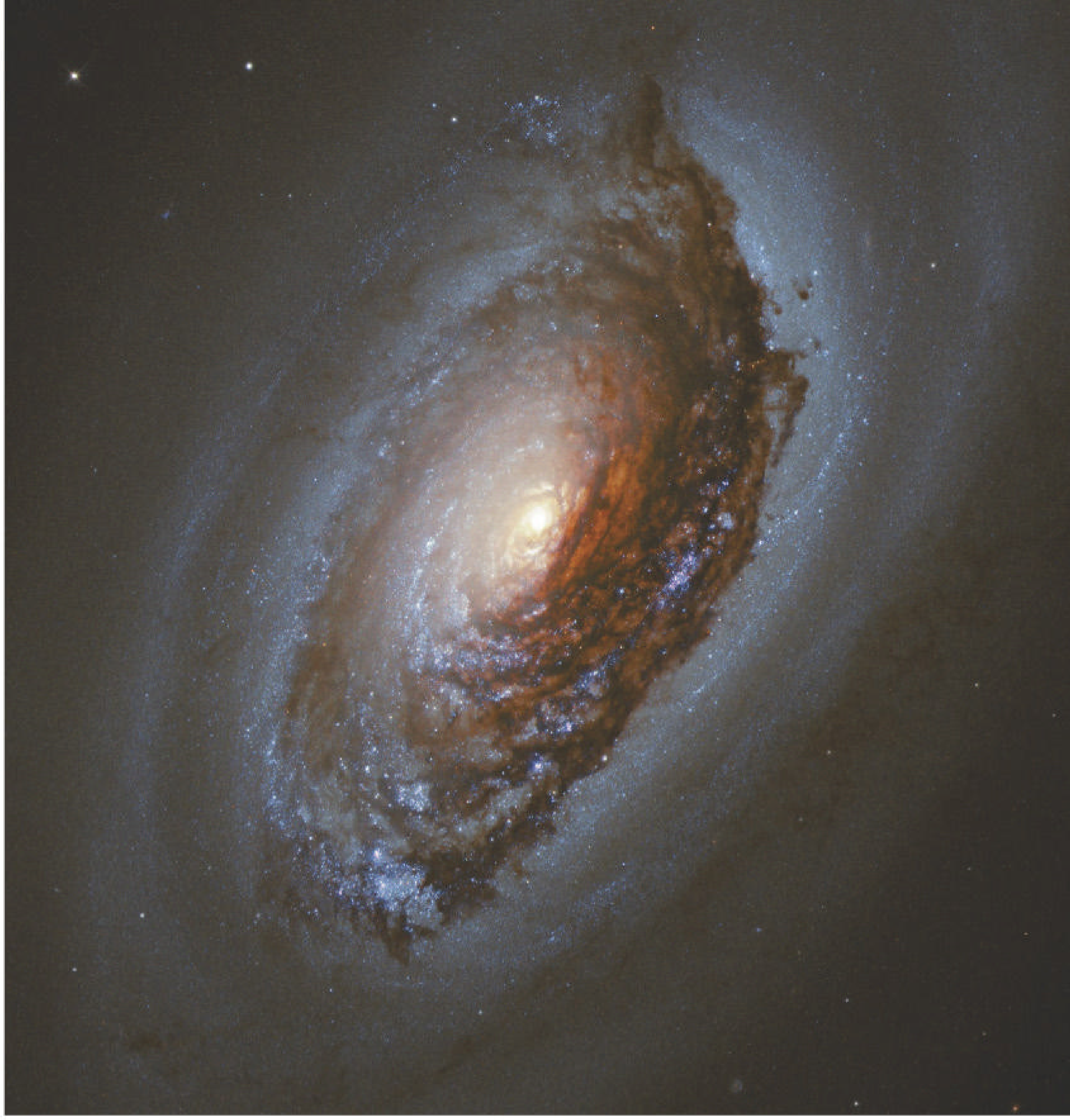
Baby star's tantrum

These wispy jets ejected across space are one of the rarer sights in the night sky, known as Herbig-Haro objects. This image captures two such objects, catalogued as HH 46 and HH 47, in the constellation of Vela (the Sails) 1,400 light years away. These emissions are ejected from newly born stars and are rapidly expelled across space at speeds of over 150 kilometres (93 miles) per second. The jets then collide with the surrounding gas, creating the bright shock waves, which have been imaged here by Hubble.

22 FEBRUARY 2021

Evil eye

The Hubble Space Telescope has captured this striking image of NGC 4826, a spiral galaxy often referred to as the 'Evil Eye' or 'Black Eye' Galaxy due to the dark cloud of dust that blankets one side. The galaxy is 17 million light years away in the constellation of Coma Berenices (Berenice's Hair) and intrigues astronomers due to its peculiar internal motion. Remarkably, the inner and outer gas regions of the galaxy rotate in opposite directions. The strange stirring of gases could be evidence of a recent merger. Where the rotating gases collide, new stars are being formed.



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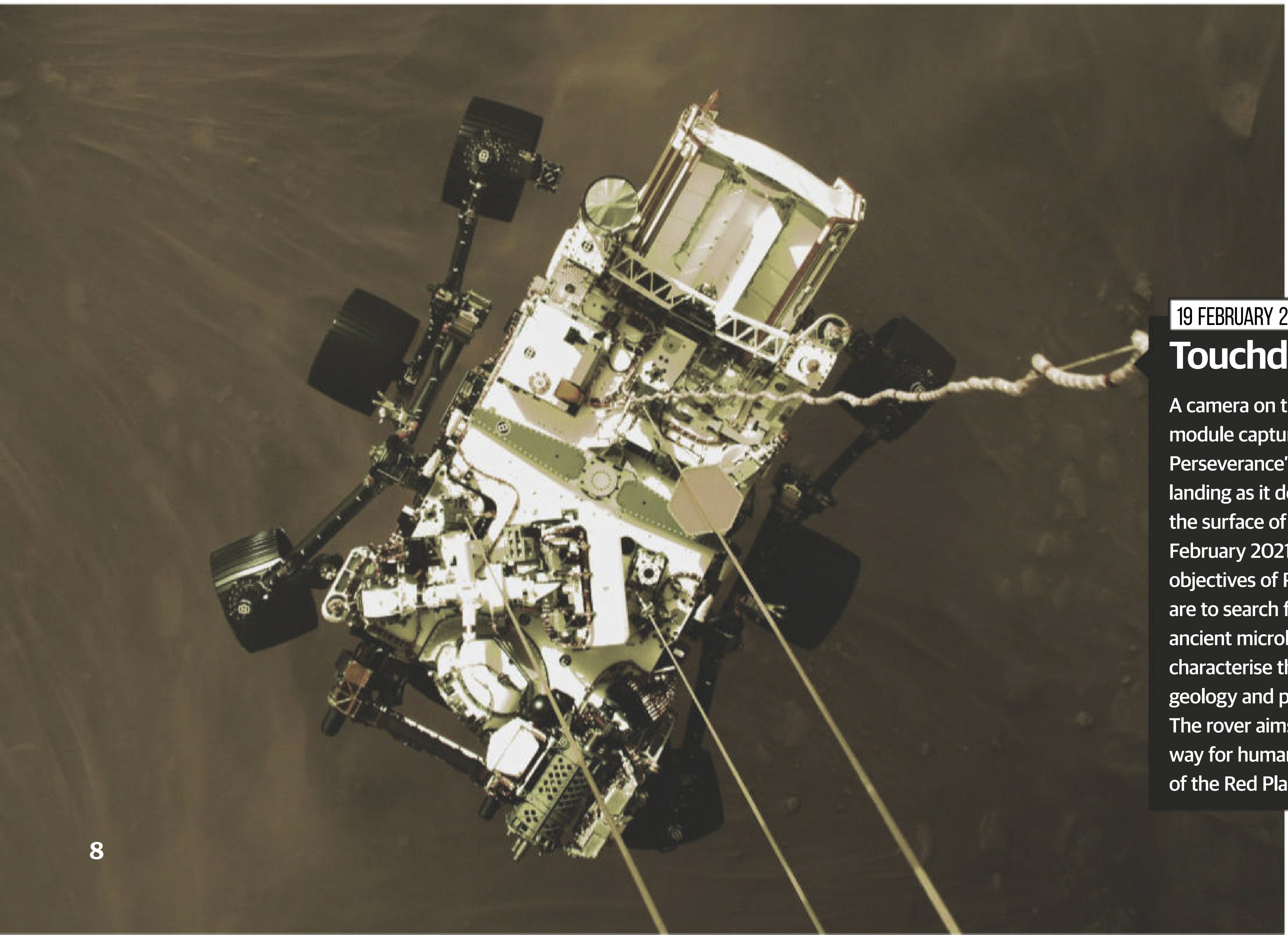

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Touchdown!

A camera on the descent module captured Perseverance's remarkable landing as it descended onto the surface of Mars on 18 February 2021. The main objectives of Perseverance are to search for signs of ancient microbial life and characterise the planet's geology and past climate. The rover aims to pave the way for human exploration of the Red Planet.

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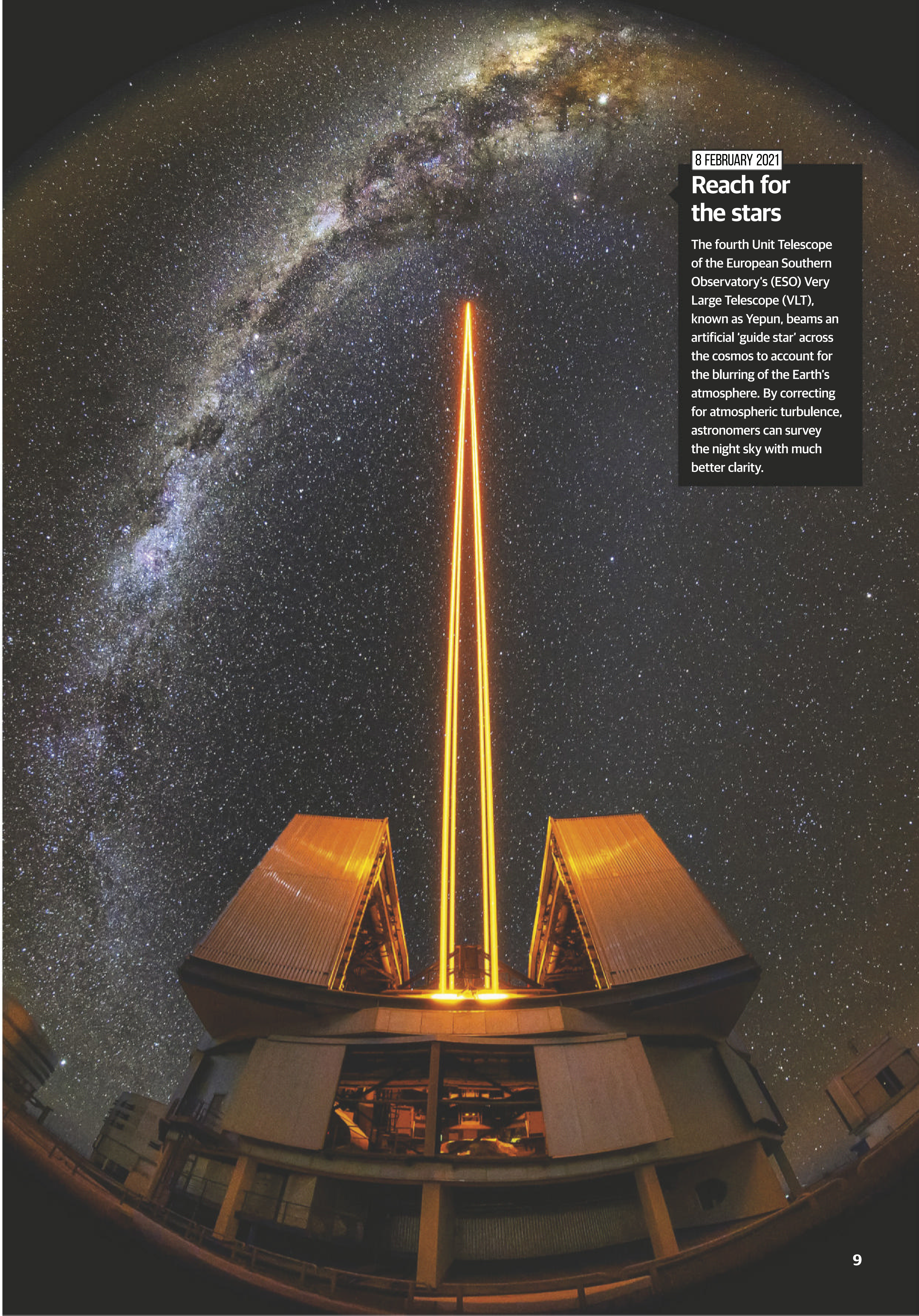

8 FEBRUARY 2021

Reach for the stars

The fourth Unit Telescope of the European Southern Observatory's (ESO) Very Large Telescope (VLT), known as Yepun, beams an artificial 'guide star' across the cosmos to account for the blurring of the Earth's atmosphere. By correcting for atmospheric turbulence, astronomers can survey the night sky with much better clarity.

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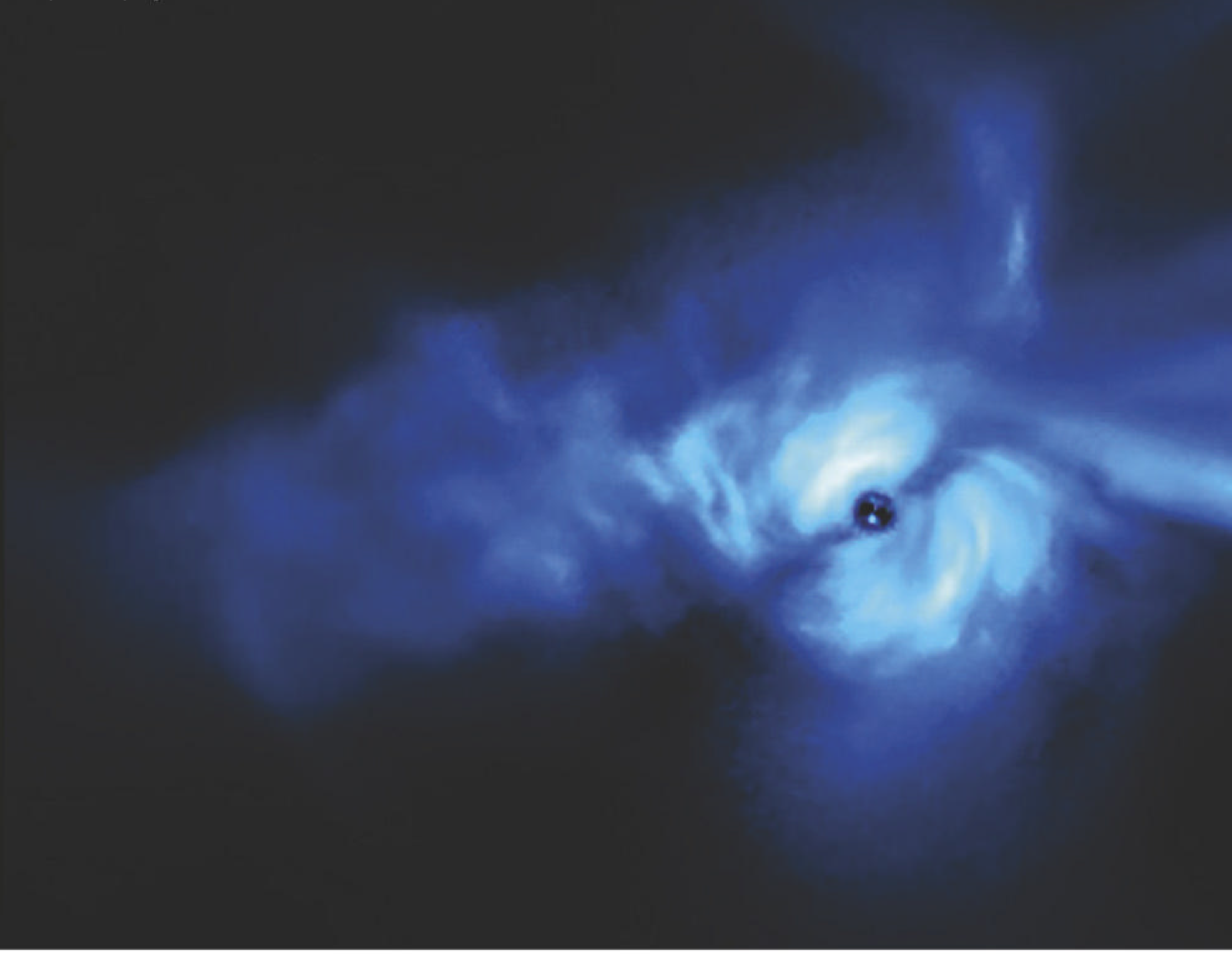

26 JANUARY 2021

Young sun takes flight

Feathery azure clouds of dust stretch out from the star SU Aurigae like a bird taking flight. This image was captured by the SPHERE instrument on the ESO's VLT.

SU Aurigae is much younger than the Sun and is encompassed by a large planet-forming disc, which has been captured here in unprecedented detail. To achieve this level of detail, the star itself has been obscured by the instrument's coronagraph, which blocks the light from the central star and allows the fainter features, such as the long dust tails, to stand out when snapped.

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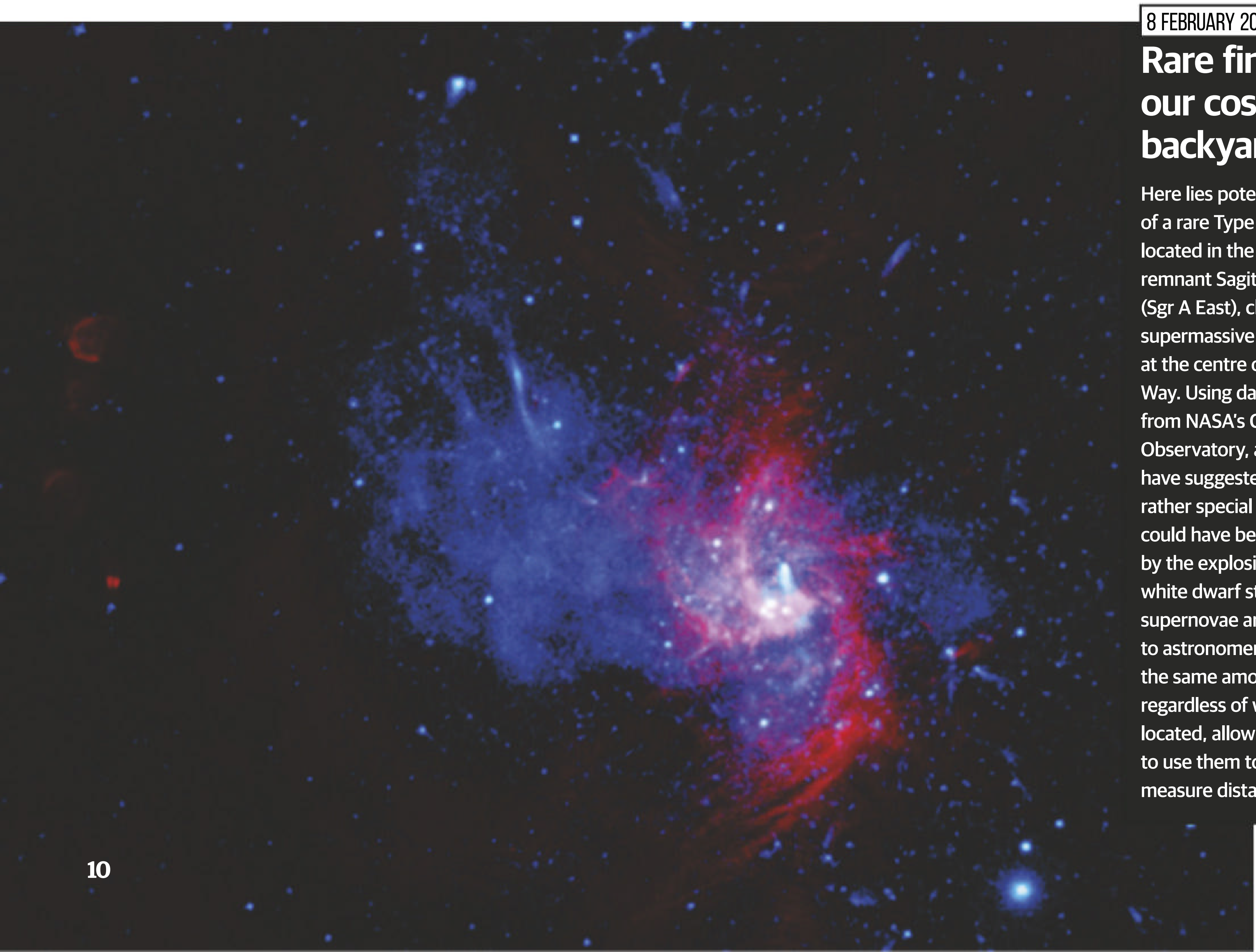

8 FEBRUARY 2021

Rare find in our cosmic backyard

Here lies potential evidence of a rare Type Ia supernova, located in the supernova remnant Sagittarius A East (Sgr A East), close to the supermassive black hole at the centre of the Milky Way. Using data collected from NASA's Chandra X-ray Observatory, astronomers have suggested that this rather special supernova could have been caused by the explosion of a white dwarf star. Type Ia supernovae are important to astronomers as they emit the same amount of light regardless of where they are located, allowing scientists to use them to accurately measure distances in space.

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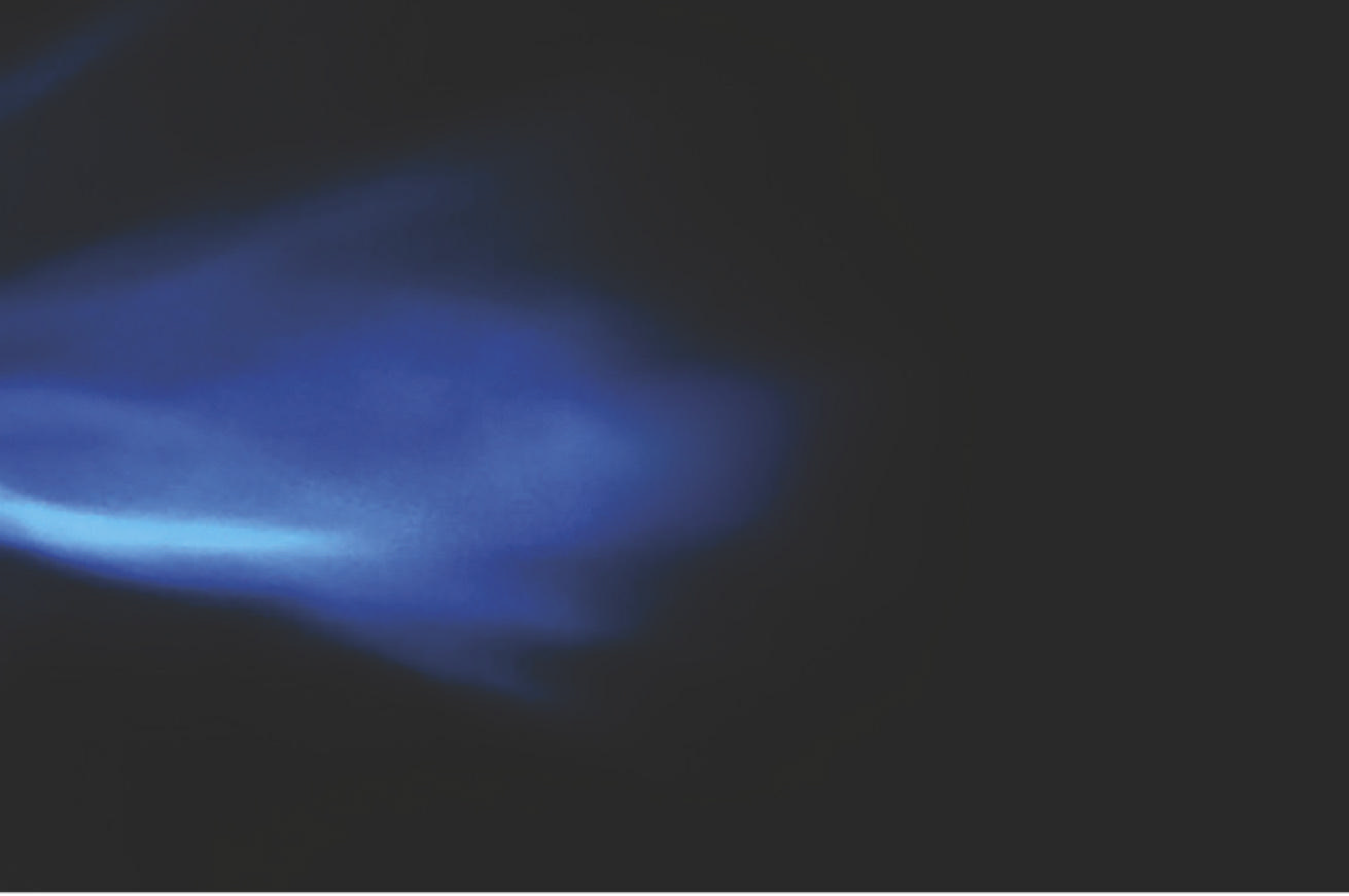

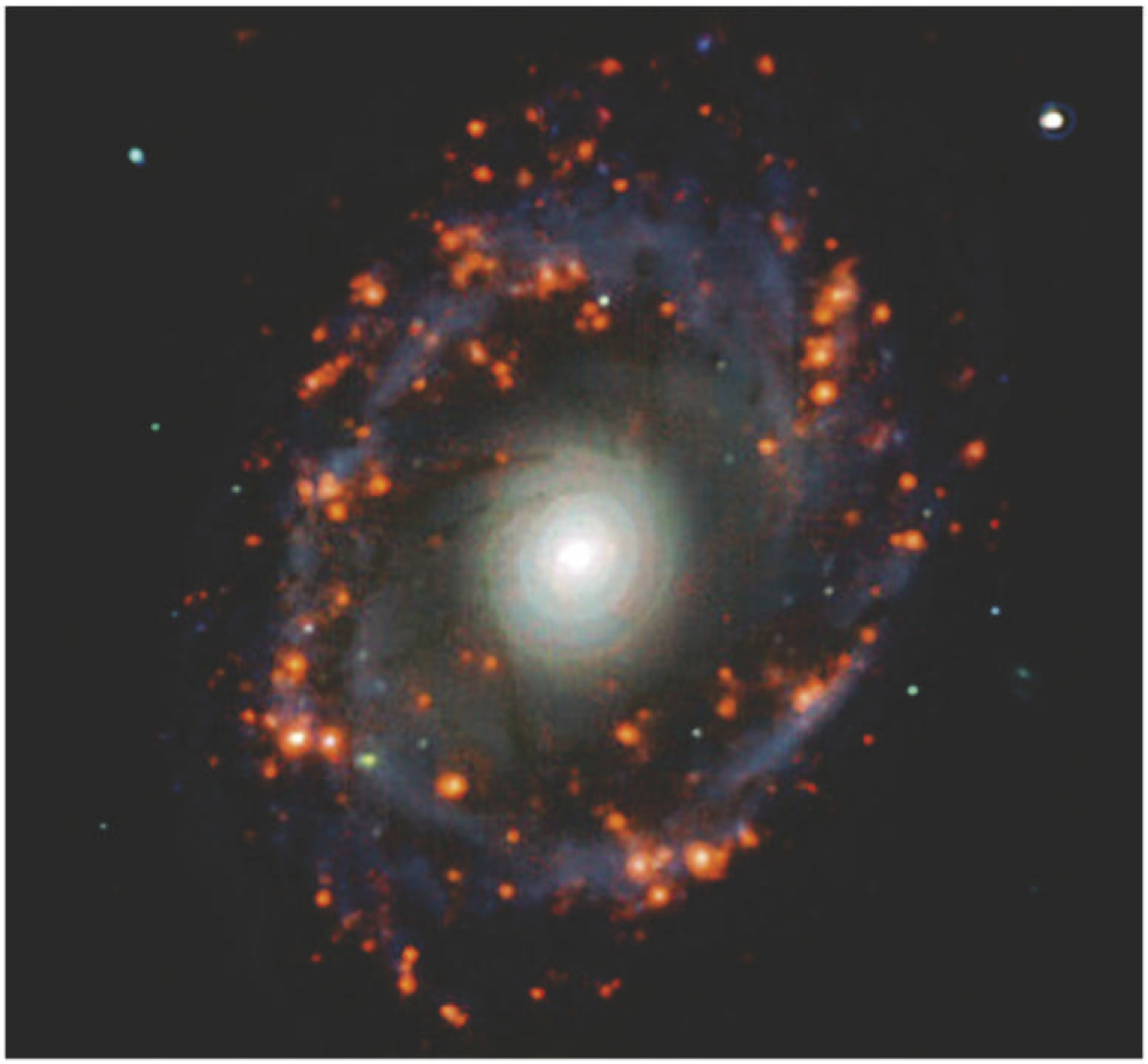

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8 FEBRUARY 2021

A pivotal moment

Zooming in on the centre of NGC 6902, astronomers have identified a nuclear ring of rapid star formation, appearing as an orange glow, with a faint, small bar of stars within.

The stars are distributed differently according to their age: the younger stars are aligned along the bar, while older stars are more dispersed. Such positions had been predicted years ago by simulations and models, but this is the first time these predictions have been confirmed with observations. NGC 6902 was discovered by John Herschel in 1836 and lies 120 million light years away from Earth in the constellation of Sagittarius.

Cosmologists create 4,000 virtual universes to solve Big Bang mystery

Words by Stephanie Pappas

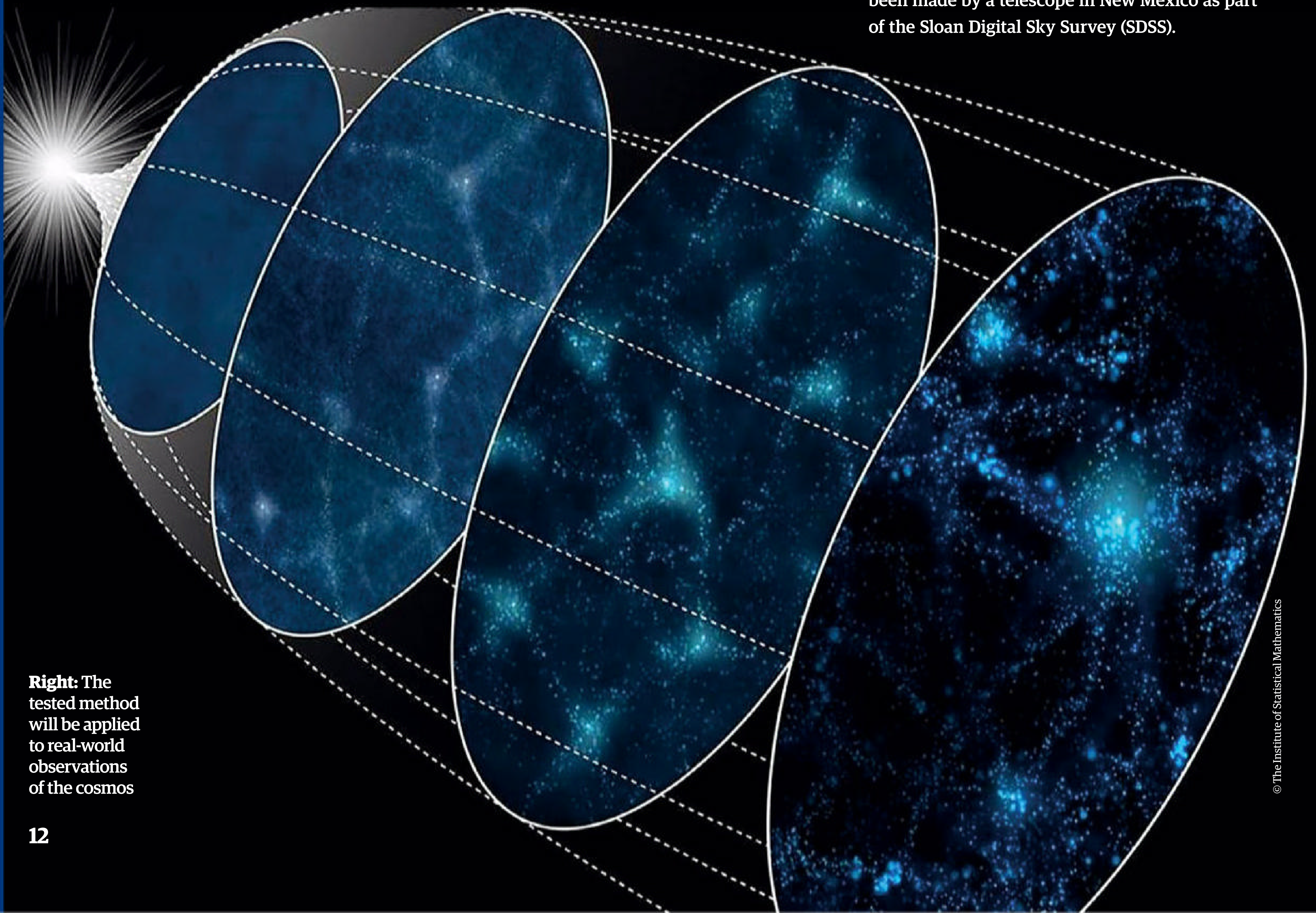
Cosmologists are pressing rewind on the first instant after the Big Bang by simulating 4,000 versions of the universe on a massive supercomputer. The goal is to paint a picture of the immediate aftermath of the Big Bang, when the observable universe suddenly expanded 1 trillion trillion times in size in the tiniest sliver of a microsecond. By applying the method used for the simulations to real observations of today's universe, researchers hope to arrive at an accurate understanding of what this inflationary period looked like.

"We are trying to do something like guessing a baby photo of our universe from the latest picture," said lead researcher Masato Shirasaki, a cosmologist at the National Astronomical Observatory of Japan (NAOJ). Today's universe shows variations in density, with some patches rich in galaxies and others relatively barren. One promising hypothesis for this uneven distribution of visible matter is that at the time of the Big Bang, there were already quantum fluctuations – or random, temporary changes in energy – in the tiny, primordial universe, Shirasaki said. When the universe expanded, these fluctuations would have expanded, too, with denser points stretching into regions of greater density than their surroundings.

Gravitational forces would have interacted with these stretched-out filaments, causing galaxies to clump along them. But gravitational interactions are complex, so trying to rewind this inflationary period to understand how the universe would have looked before is very challenging. Cosmologists essentially need to remove the gravitational fluctuations from the equation.

The researchers developed a reconstruction method to do just that. To find out if the reconstruction was accurate, however, they needed a way to test it. They used NAOJ's ATERUI II supercomputer to create 4,000 versions of the universe, all with slightly different initial density fluctuations. The researchers allowed these virtual universes to undergo their own virtual inflations and then applied the reconstruction method to them to see if it could get them back to their original starting points.

"We find that a reconstruction method can reduce the gravitational effects on observed galaxy distributions, allowing us to extract the information of initial conditions of our universe in an efficient way," Shirasaki said. The reconstruction has been applied to real-world galaxy data before, he added, but the new study shows that it can work on the universe's inflation period. The next step, Shirasaki said, is to apply the reconstruction to real observations of the cosmic web. Those observations have already been made by a telescope in New Mexico as part of the Sloan Digital Sky Survey (SDSS).



Right: The tested method will be applied to real-world observations of the cosmos

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'Ghostly' neutrino from star-shredding black hole reveals cosmic particle accelerator

Words by Charles Q. Choi

A ghostly particle that smashed into Antarctica in 2019 has been traced back to a black hole tearing apart a star while acting like a giant cosmic particle accelerator. Scientists investigated the extremely high-energy neutrino they spotted on 1 October 2019 using the IceCube Neutrino Observatory.

"It smashed into the Antarctic ice with a remarkable energy of more than 100 teraelectronvolts," said researcher Anna Franckowiak. "For comparison, that's at least ten times the maximum particle energy that can be achieved in the world's most powerful particle accelerator, the Large Hadron Collider." To discover the origins of such a powerful neutrino, the scientists traced its path through space. They found that it likely came from the galaxy designated 2MASX J20570298+1412165 in the constellation Delphinus, the Dolphin, and is located about 750 million light years from Earth.

About six months before scientists detected the high-energy neutrino, astronomers witnessed a glow from this galaxy using the Zwicky Transient Facility on Mount Palomar in California. This light likely came from a black hole shredding a star, a so-called tidal disruption event dubbed AT2019dsg. This discovery marks only the second time scientists have traced a high-energy neutrino back to its source.

Above: A tidal disruption event accelerated the particle

Lumpy 13.6-kilogram meteorite that crashed in Sweden recovered in local village

Words by Stephanie Pappas

A half-melted hunk of iron-rich rock found in Uppsala, Sweden, is part of a meteorite that fell there in November 2020. The lumpy meteorite is about the size of a loaf of bread, and weighs around 13.6 kilograms. It was once part of a larger space rock, probably weighing more than 8.1 tonnes, that created a dramatic fireball over Uppsala on 7 November 2020.

After that fireball impacted, scientists at the Swedish Museum of Natural History calculated the likely landing site and found some small fragments of iron meteorite near the village of Ådalen. These tiny metallic fragments were only about three millimetres (0.11 inches) long, but the investigation also turned up a boulder and a tree root that had clearly been hit by something heavy.

Stockholm geologists Andreas Forsberg and Anders Zetterqvist headed back to the site and found a much larger piece - likely the one that smashed the boulder. The piece was about 70 metres (230 feet) from the area where the fragments were found, partially buried in moss. One side is flattened and cracked, likely from the collision, and the meteorite is pockmarked with circular depressions. These depressions are common in iron meteorites, according to the museum, and they form when the space rock partially melts during its passage through the atmosphere.

"It is the first sure example of a newly fallen iron meteorite in our country," said Swedish Museum of Natural History curator Dan Holtstam. "It's also the first time that any meteorite fragments linked to an observed fireball have been recovered in Sweden for 66 years".

© Andreas Forsberg/Anders Zetterqvist

Left: The iron-rich chunk of space rock was recovered after a fireball event

Right: The DART mission will be purposefully crashed into a binary asteroid system

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NASA delays launch of DART mission

Words by Samantha Mathewson

NASA has delayed the launch of its first-ever planetary defence mission, aimed at deflecting potentially hazardous asteroids from colliding with Earth. The Double Asteroid Redirection Test (DART) will send a spacecraft to test crash into near-Earth binary asteroid system Didymos in 2022.

NASA announced that this year's primary launch window of 21 July to 24 August is no longer an option. Instead the space agency is targeting a backup window that opens 24 November and runs to 15 February 2022.

The decision to postpone the launch was made by NASA Science Mission Directorate (SMD) senior leadership following a risk assessment of the DART project schedule. Delaying the launch of the mission will not affect the spacecraft's arrival at its target in October 2022.

The risk assessment revealed technical issues with two major components of the spacecraft, including its main instrument, the Didymos Reconnaissance and Asteroid Camera for Optical navigation (DRACO), and its Roll Out Solar Arrays (ROSA). The DRACO imager needs to be reinforced to ensure it can withstand launch, while the solar arrays are delayed following supply chain issues.

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European Space Agency announces call for 'parastronauts' with disabilities

Words by Chelsea Gohd

The European Space Agency (ESA) is diversifying its astronaut pool with its first call for astronauts open to candidates with physical disabilities. In this call for new astronauts, the agency's first recruitment drive in over a decade, the ESA announced that it plans to accept four to six career astronauts, who will be permanent ESA staff, and about 20 'reserve astronauts', who could fly for shorter missions to destinations like the International Space Station.

As part of this call for astronaut applicants, ESA director general Jan Wörner revealed that the agency is aiming to bring its first 'parastronaut,' or astronaut with physical disabilities, on board. "The ESA is ready to invest in defining the necessary adaptations of space hardware in an effort to enable these otherwise excellently qualified professionals to serve as crew members on a safe and useful space mission," the agency said.

For this parastronaut, who would be the first astronaut with physical disabilities selected not just by the ESA, but in history, the agency is "looking for individual(s) who are psychologically, cognitively, technically and professionally qualified to be an astronaut, but have a physical disability that would normally prevent them from being selected due to the requirements imposed by the use of current space hardware". The ESA consulted with the Paralympic Committee to determine exactly which physical disabilities would work consistently with space missions.

Above: The ESA is the first agency to announce a more inclusive astronaut selection process

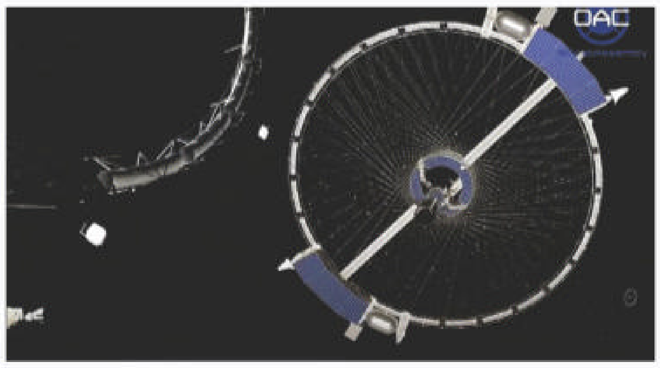
Company plans to start building private Voyager space station with artificial gravity in 2025

Words by Jeff Spry

Orbital Assembly Corporation (OAC) recently unveiled new details about its ambitious Voyager Station, projected to be the first commercial space station operating with artificial gravity. OAC, a manufacturing firm centred on the colonisation of space, discussed Voyager during a press junket in January. The virtual event served as an update for interested investors, marketing partners and enthusiastic holidaymakers hoping to someday book a room aboard the rotating Voyager Station.

During the event, the company revealed its schedule for the next chapter of human space exploration. Its team of skilled NASA veterans, pilots, engineers and architects intends to assemble a 'space hotel' in low-Earth orbit that rotates fast enough to generate artificial gravity for holidaymakers, scientists, astronauts and anyone else who wants to experience off-Earth living.

Voyager Station is patterned after concepts imagined by legendary rocket scientist Wernher von Braun, one of the main orchestrators of NASA's Apollo program. The wheel-shaped habitat will spin with an angular velocity high enough to create Moon-like levels of artificial gravity for its occupants. This shining technological ring will feature amenities ranging from themed restaurants, viewing lounges, cinemas and concert venues to bars, libraries, gyms and a health spa. If realised, Voyager would become the biggest human-made structure in space, fully equipped to accommodate up to 400 people.



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Left: The 'space hotel' will spin so fast that it generates artificial gravity

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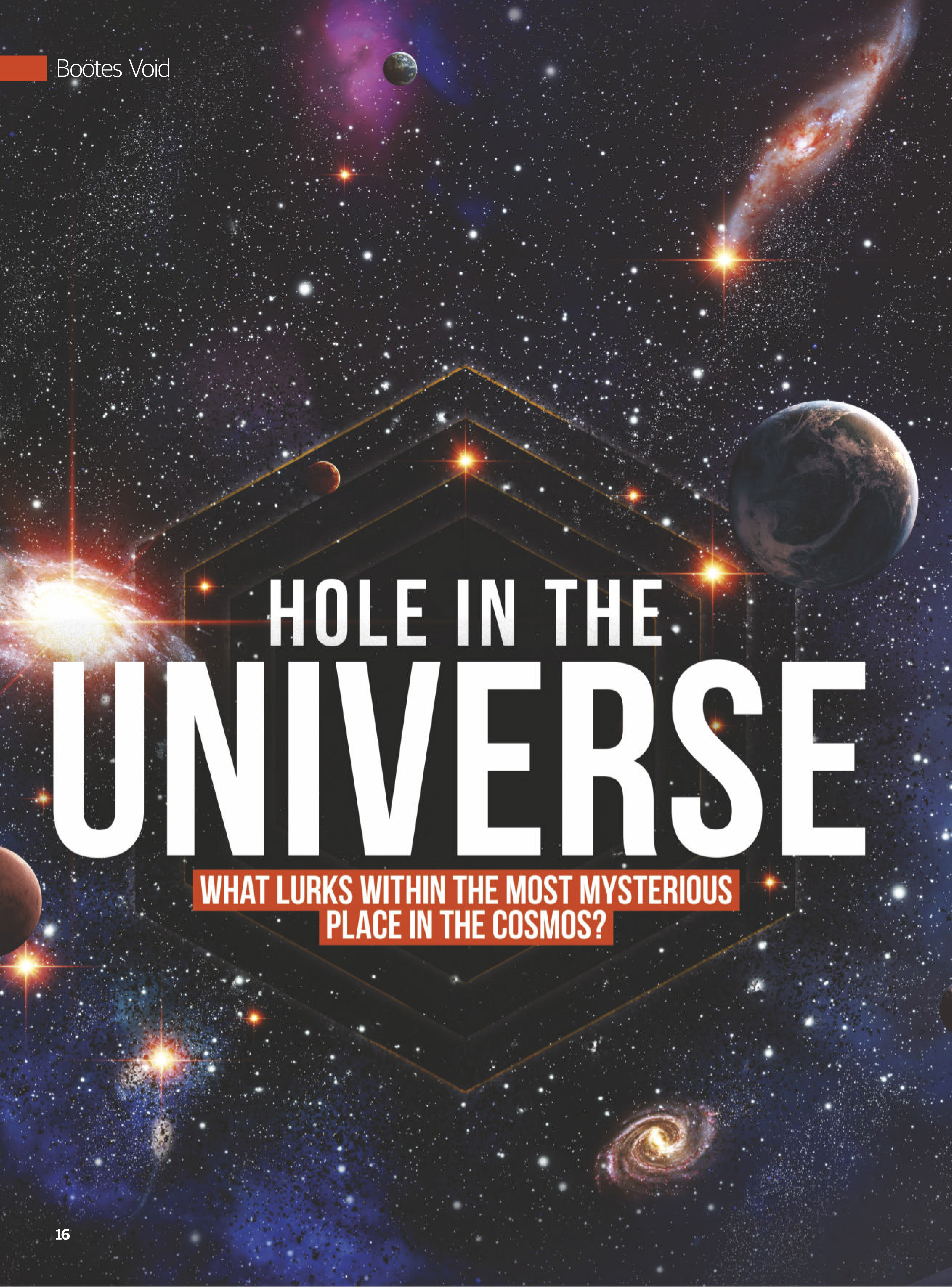


HOLE IN THE UNIVERSE

WHAT LURKS WITHIN THE MOST MYSTERIOUS PLACE IN THE COSMOS?

"If the Milky Way had been in the centre of the Boötes Void , we wouldn't have known there were other galaxies until the 1960s." This was a quote from American astronomer Greg Aldering in an article for *Discover* magazine in 1995. He was talking about a region of space that appears to be a cosmological 'dead zone', containing very few stars or galaxies.

Galaxies have been observed for hundreds of years with telescopes, while some, such as Andromeda, Triangulum and the Magellanic Clouds, have been visible to the naked eye throughout human existence. But inside a cosmic void such as Boötes, none of that would have been the case until the development of modern instruments. The Milky Way would have been an anomaly inside a dark bubble of 'nothing'. As it happens, our galaxy exists among others in a cluster, called the Local Group.

The first void was discovered in 1978 by two separate teams: one at the Kitt Peak National Observatory in Arizona, and the other at the Tartu Astrophysical Observatory in Estonia. Looking at the foreground region of Abell 1656 and Abell 1367 - together called the Coma Supercluster - 300 million light years away, they noticed an unusual absence of galaxies.

Then, in 1981, Robert Kirshner and others discovered a large galaxy-free zone centred 700 million light years away in the constellation of Boötes. Looking at the redshift of surrounding galaxies - the degree to which galaxies' light spectra are reddened due to their recession speeds, and thus distances, a result of the expansion of space - they noticed a gap at around 1,500 kilometres (932 miles) per second. Follow-up work constrained this to 1,200 to 1,900 kilometres (745 to 1,180 miles) per second. There were very few galaxies with those velocities. This roughly spherical 330 million light year expanse, disguised by surrounding galaxies, had finally shown itself.

The Boötes Void is roughly 3,300 times the size of the Milky Way, and is sometimes called a 'supervoid'. If the entire observable universe was one metre (3.2 feet) wide, then Boötes would span about 2.7 millimetres (0.1 inches). In cosmological terms, that's vast. By 1997 a total of 60 galaxies had been discovered within - roughly 33 times fewer than would normally be expected for other parts of space. Boötes isn't truly barren, but it isn't lush.

© Tobias Roetsch

INGREDIENTS OF THE UNIVERSE VS VOIDS

THE UNIVERSE

Dark matter

Sites of invisible dark matter were the gravitational 'seeds' that attracted the universe's primordial hydrogen and helium gas. This dark matter formed shortly after the Big Bang.

Gas

Largely made of primordial hydrogen (75 per cent) and helium (24 per cent), gas concentrates in cosmic filaments, where large concentrations of dark matter are already present. This then collapses to form galaxies full of stars.

Dust

When the largest stars explode as supernovae, they spread heavy elements into intergalactic space. Some of this forms into molecules, including organic compounds. Some then forms into dust grains.

Stars

Residing in the stellar metropolises of galaxies, stars illuminate a web-like structure on the largest cosmic scales, consisting of clusters, filaments, arcs, sheets and walls.

VOIDS

Dark energy

Dark energy, comprising 68 per cent of the universe's energy density, is responsible for the accelerated expansion of space. Changes in a void's shape will partly be down to dark energy.

Neutrinos

Because they hardly interact with normal matter, neutrinos travel the entire universe almost unhindered. But their masses can affect the number of small and large voids, something that is being explored further.

Dwarf galaxies

Of the few galaxies that do reside in voids, many – if not all – are dwarf galaxies with slow evolutions.

> "DEEP INSIDE WE DO FIND SOME MATERIAL, LIKE DARK MATTER AND SMALL, DIM DWARF GALAXIES" PAUL M. SUTTER

But are voids fundamentally different from other areas of space? "Voids are almost completely empty. You can go millions of light years without encountering anything more than a hydrogen atom," says cosmologist, science educator and author Paul M. Sutter. "But deep inside we do find some material, like dark matter and small, dim dwarf galaxies. It's the same stuff that's in the clusters and filaments, just less of it."

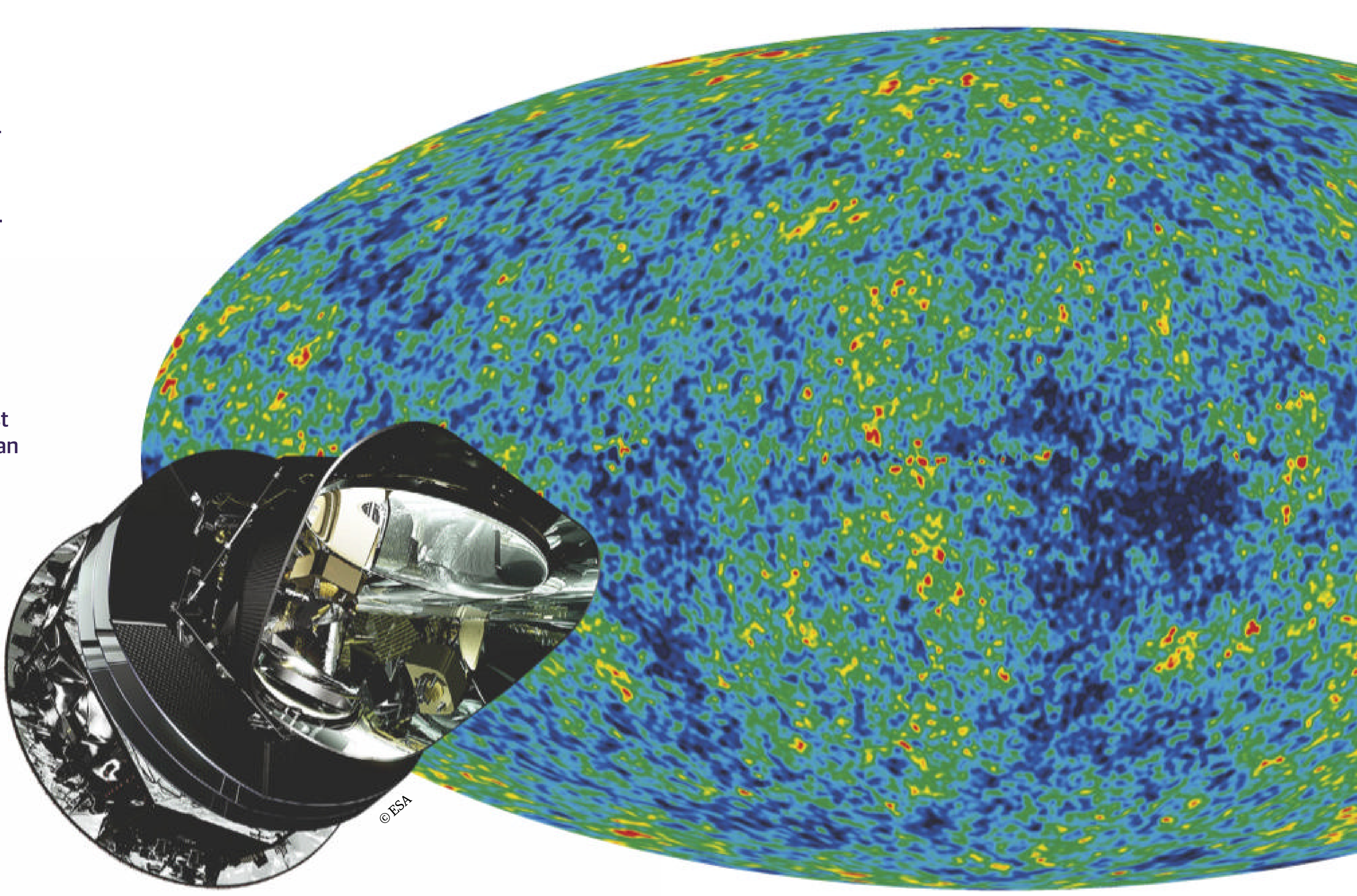
One person who studies galaxy formation in voids is Professor Rien van de Weygaert of Groningen University in the Netherlands. "The mass available to protogalaxies in voids is far less than in more moderate cosmic environments like filaments," he says. "Voids are low density, and mass is continuously streaming out. The mass clumps in voids not only start out lower mass, but are also not able to accrete much during their evolution." This is borne out of simulations Weygaert has conducted with numerous colleagues. "Because of the lower mass available to the void galaxies, the gravitational contraction and collapse of these objects proceeds more slowly." The team is studying the star formation history of these void galaxies, allowing researchers to have a better understanding of their assembly, which in turn will provide direct information on the cosmological background. But how did voids themselves form?

The best theory involves quantum fluctuations during the Big Bang growing enormously during a rapid expansion event called inflation. 380,000 years later, the universe switched from being a hot, dense plasma of subatomic particles to a transparent universe of atoms – an event known as recombination. That's because as the universe expanded it became less dense, allowing the particles to form atoms. This 'froze' into place any density fluctuations that had originated during the Big Bang. As the universe continued expanding, areas of high density became sites of galaxy formation, while low-density areas saw minimal formation, becoming voids. Boötes is thought to be composed from smaller voids, otherwise it couldn't have attained its size in the time that it did. So does this mean there are other voids?

"There are actually many voids; the universe is really empty," says Dr David Alonso of Oxford University. In fact, voids account for 70 per cent of the observable universe's volume. Alonso and his colleagues studied a particular phenomenon using data from the Sloan Digital Sky Survey's (SDSS) Baryon Oscillation Spectroscopic Survey (BOSS) and the European Space Agency's (ESA) Planck telescope. BOSS mapped the distributions of red galaxies and quasars. The Planck telescope was a space-borne observatory that mapped the relic radiation from the recombination era, which the expansion of space has stretched over 13.769

Below: The Planck space telescope mapped the background radiation of the universe, essential for understanding cosmic voids

Below main: The CMB provided the blueprint for the universe's large-scale structure, including galaxy clusters and voids



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WHAT'S HAPPENING AT THE BOÖTES VOID?

This large, relatively empty expanse was hiding in plain sight

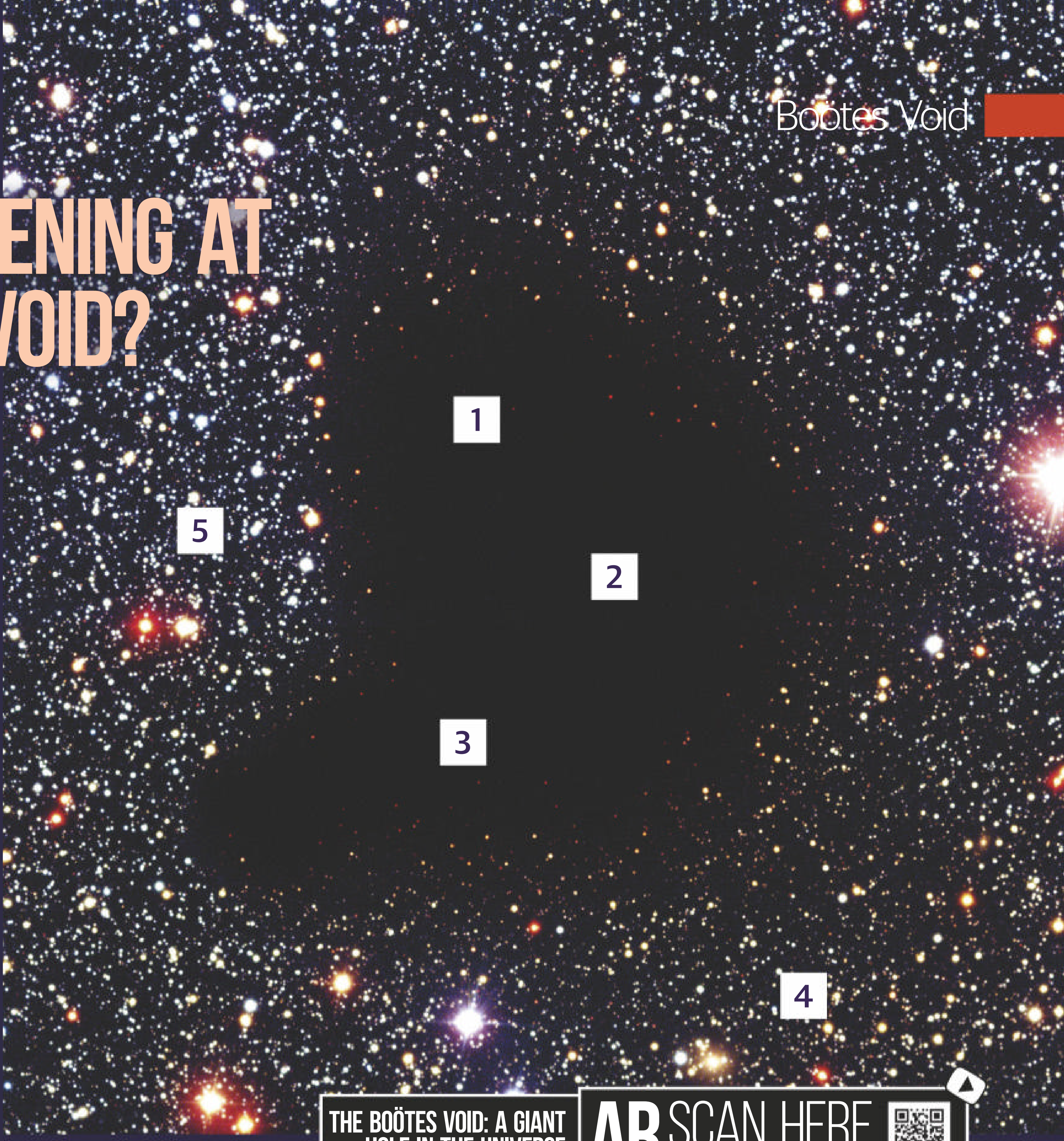
1 Voids grew from seeds
Quantum fluctuations from the Big Bang expanded with the universe to create voids.

2 Smaller voids coalesced
It's believed that smaller voids combined to form the 330 million light year-diameter Boötes 'supervoid'.

3 Dark energy dominates
Dark energy plays a significant role in shaping and maintaining voids such as Boötes.

4 Dark matter attracts
Areas of dark matter, denser than in voids, attracted more normal matter to them.

5 Galaxy factories
Gravity caused the matter in denser areas to collapse into observable galaxies and clusters.



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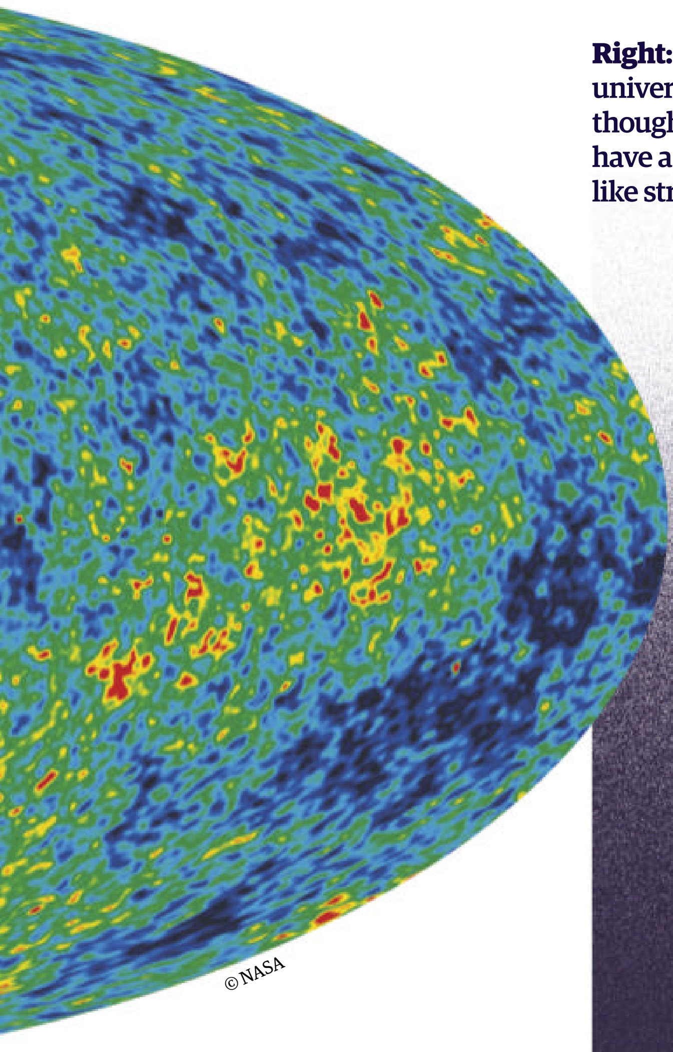
THE BOÖTES VOID: A GIANT HOLE IN THE UNIVERSE

AR SCAN HERE



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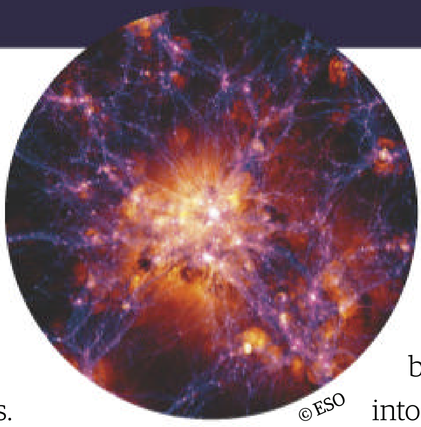

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Right: The universe is thought to have a web-like structure

billion years into the microwave region, hence its name: the cosmic microwave background (CMB).

Alonso's team used the BOSS data to identify and map 774 cosmic voids. These were all in the Southern Hemisphere, so Boötes wasn't included. They then stacked them onto Planck's CMB data. They were studying the Sunyaev-Zel'dovich effect, where photons of the CMB are boosted by high-energy electrons in galaxy clusters. This causes distortions in the CMB that reveal the locations of clusters and voids. They compared the energy of the observed CMB photons from voids to those of modelled values. "We figured out that we can use voids to measure the mean gas pressure as long as they're sufficiently 'empty'," says Alonso.

There are hints that the void gas is slightly warmer than expected. "The most likely causes are either a statistical fluctuation in the data, or small errors in the model used to describe the gas pressure in voids," says Alonso, but he points out that the data is tentative. Another explanation is that powerful cosmic jets from supermassive black holes could be injecting energy into space, which then shows up as a slight overtemperature in void gas. The mystery could be solved soon. Alonso says that the Atacama Cosmology Telescope or the Simons Observatory should obtain cleaner CMB mapping data that could then be combined with future galaxy surveys, like that of DESI, the Dark Energy Spectroscopic Instrument.

Much of the action in the universe seems to be in galaxy clusters, superclusters and filaments, so why go to voids for answers at all? "Voids are the ultimate time capsule for the universe," says Sutter. "Unlike clusters and filaments, they've barely changed over the course of billions of years. They've preserved a memory of the early universe, and by looking at voids we can see what it was like back then." In effect, voids are pristine archaeological sites for cosmologists wanting to

WHERE IS THE BOÖTES VOID?

Boötes Void

Size: 330 million light years

Object type: Cosmic void

1 The void's centre lies 700 million light years away from Earth. It was discovered in 1981, and the Hercules Supercluster forms one edge.

Coma

Size: 20 million light years

Object type: Supercluster

2 In Coma Berenices lies this supercluster containing over 3,000 galaxies. It's the central component of the Coma Great Wall and is also part of the Coma Filament.

Corona Borealis

Size: 150 million light years

Object type: Cosmic void

3 This void lies next to the Microscopium Void and is surrounded by the Ophiuchus, Hercules and Centaurus superclusters. It is next to the Coma Great Wall.

Hydra-Centaurus

Size: 250 million light years

Object type: Supercluster

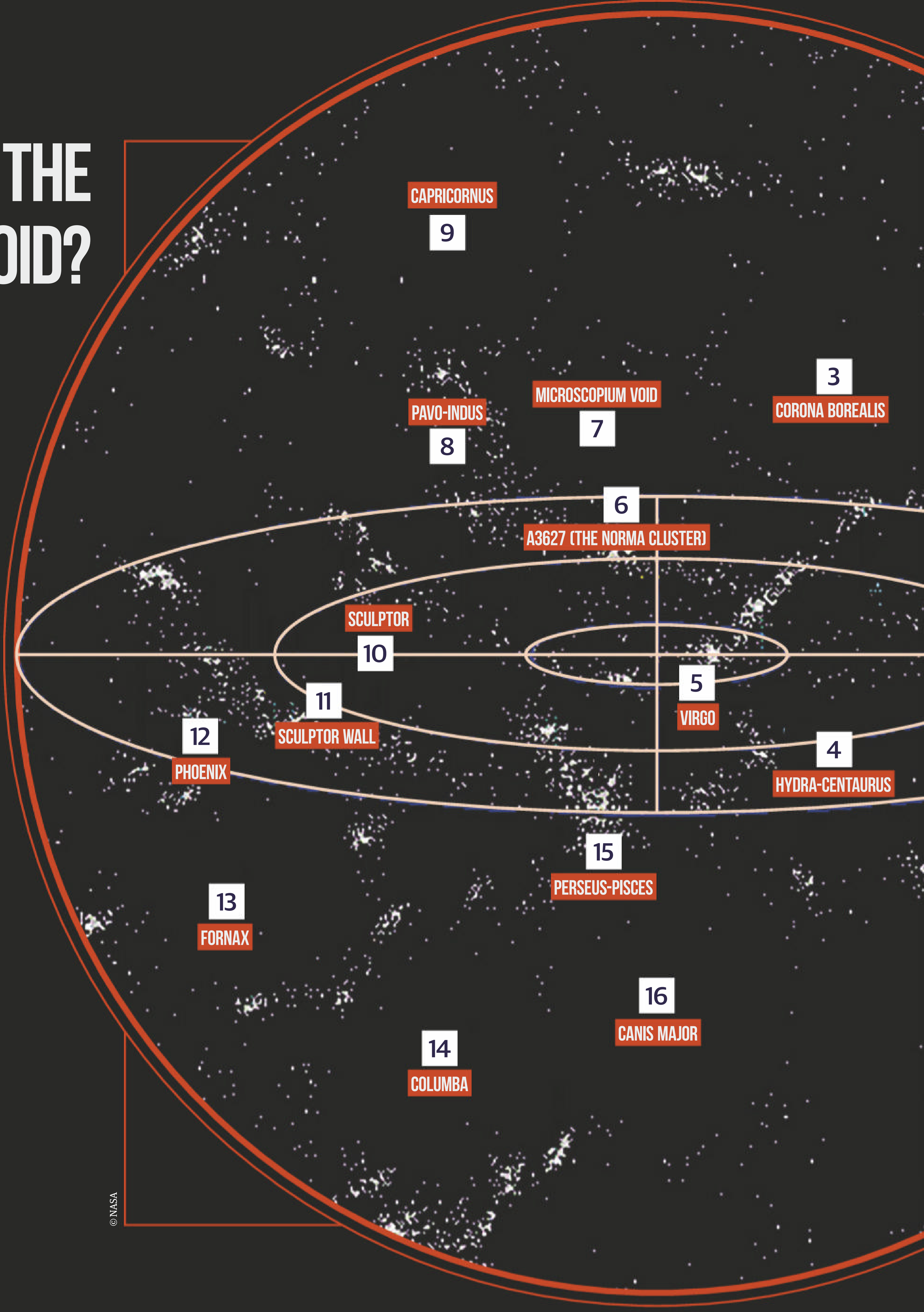
4 A twin-lobed supercluster that's 150 million light years away at its closest. It is the nearest such structure to our home supercluster of Virgo.

Virgo

Size: 110 million light years

Object type: Supercluster

5 The supercluster in which we reside contains the Local Group of galaxies, of which we are a part. Virgo is 110 million light years in size with a mass of 1.48 x 10^{15} solar masses.



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A3627 (the Norma cluster)

Size: Unknown

Object type: Supercluster

6 220 million light years away, Norma is largely obscured behind a region of the Milky Way called the Zone of Avoidance.

Microscopium Void

Size: Unknown

Object type: Cosmic void

7 A roughly rectangular-shaped region of space near the Corona Borealis Void and the Capricornus Void, it lies above the Norma Supercluster.

Pavo-Indus

Size: Unknown

Object type: Supercluster

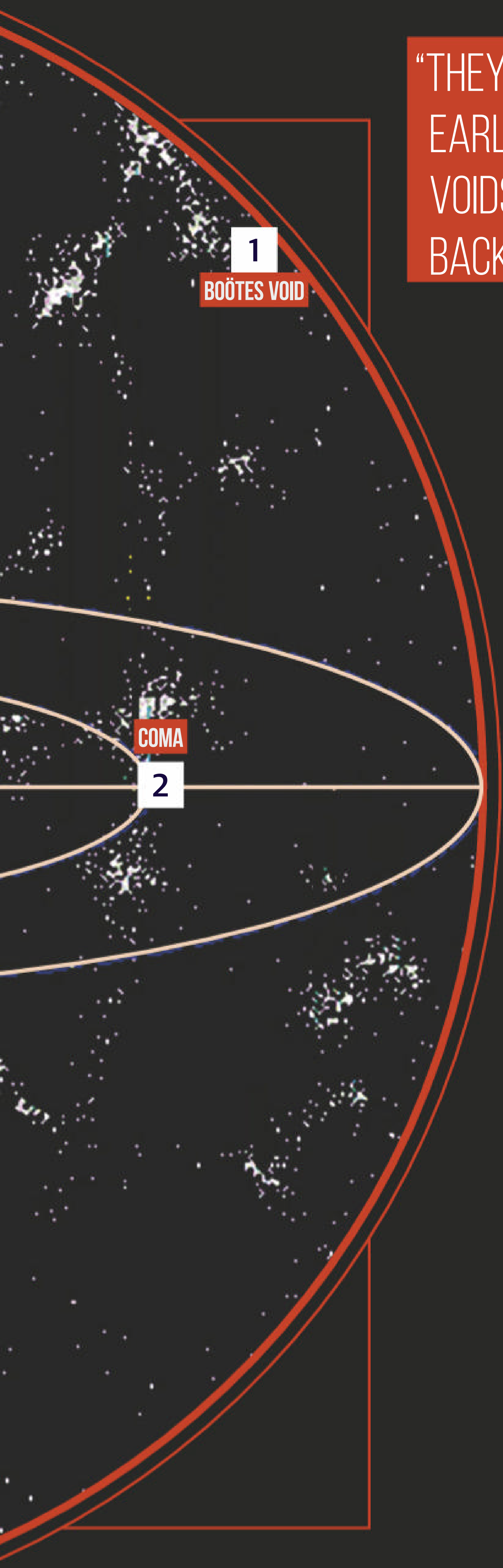
8 Located 196 million light years away, Pavo-Indus is a lobe of the much larger Laniakea Supercluster, which was discovered in 2014.

Capricornus

Size: 230 million light years

Object type: Cosmic void

9 A 230 million light year-wide void in the Capricornus constellation, making it one of the biggest ever known, but is smaller than Boötes.



> “THEY’VE PRESERVED A MEMORY OF THE EARLY UNIVERSE, AND BY LOOKING AT VOIDS WE CAN SEE WHAT IT WAS LIKE BACK THEN” PAUL M. SUTTER

Canis Major

Size: Unknown

Object type: Cosmic void

16 This lies next to the Perseus-Pisces Supercluster on one side and close to the Hydra lobe of the Hydra-Centaurus Supercluster on the other.

Perseus-Pisces

Size: Unknown

Object type: Supercluster

15 A supercluster lying 250 million light years away, it also forms part of the 1 billion light year-long Perseus-Pisces Filament of galaxies.

Columba

Size: 150 million light years

Object type: Cosmic void

14 Similar in size to the Corona Borealis Void, Columba lies between the Fornax and Canis Major voids. The associated constellation lies between Caelum, Canis Major and Puppis.

Fornax

Size: Unknown

Object type: Cosmic void

13 This roughly spherical void lies beyond the Sculptor Wall and next to the Columba Void, with only a thin stream of galaxies separating them.

Phoenix

Size: Unknown

Object type: Supercluster

12 Part of the Sculptor Wall, this lies next to the Sculptor Void in the Phoenix constellation. The Phoenix Supercluster is 400 million light years from Earth.

Sculptor Wall

Size: 326 million light years

Object type: Supercluster

11 Also called the Sculptor Supercluster and the Southern Great Wall, it measures 326 by 228 by 33 million light years and is one of a handful of cosmic ‘wall’ structures.

Sculptor

Size: Unknown

Object type: Cosmic void

10 Many objects in the universe are named after Sculptor. This void is separated from the supposed Eridanus Void by a sheet of galaxies and lies next to the Sculptor Wall.

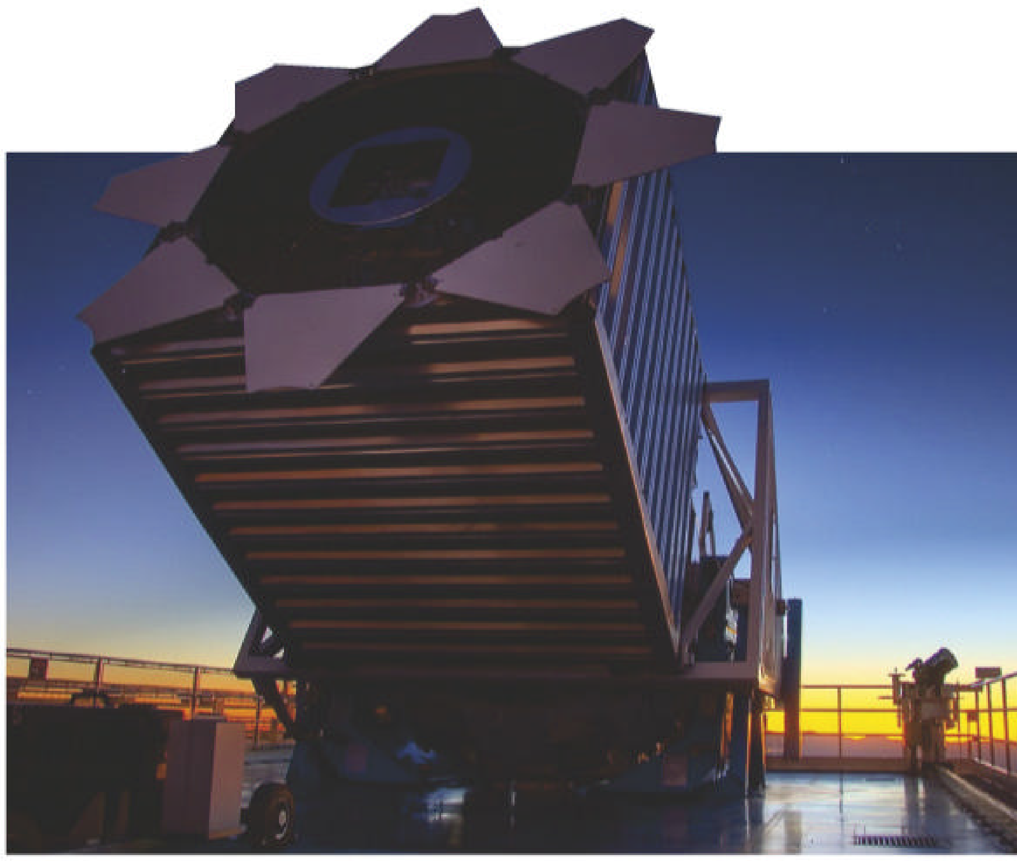
know about the evolution of the universe. Voids could help uncover one of the biggest mysteries in cosmology. “Voids are the only places that are dominated by dark energy, the mysterious force that is accelerating the expansion of the universe. By looking at how they evolve, we can gain clues to understanding how this acceleration works,” says Sutter. He himself was part of a team that probed dark energy by counting voids.

By studying dark energy in this way, you can test models of the Big Bang. The currently accepted model for our universe is called LCDM, or Lambda cold dark matter. As Weygaert says: “The LCDM is a hierarchical model of the build-up of structure. The first objects to form have small masses. These subsequently merge into ever larger masses. When we look at the abundance of low-mass objects that results from this process and compare it to the large objects, we see a strong divergence towards lower masses. There are far more low-mass than high-mass galaxies.”

Pauline Vielzeuf of the International School of Advanced Studies, Italy, and Andras Kovács of the Instituto de Astrofísica de Canarias led a large international team to look for gravitational lensing signals in voids. Gravitational lensing, a consequence of Einstein’s general theory of relativity, states that energy and mass can gravitationally bend the path of a photon in the vicinity, like a lens. The team identified voids using the Dark Energy Survey (DES) - which like BOSS mapped the southern sky - and stacked lensing maps from the Planck telescope on top. But getting good observational data is challenging, so they used supercomputer simulations to optimise and calibrate the measurements. The emergent shape and amplitude of the void lensing signal then gave them a roadmap for real-world measurements.

They found that “the lensing effect of voids

Below: The SDSS created a 3D map of galaxy clusters and voids in the universe



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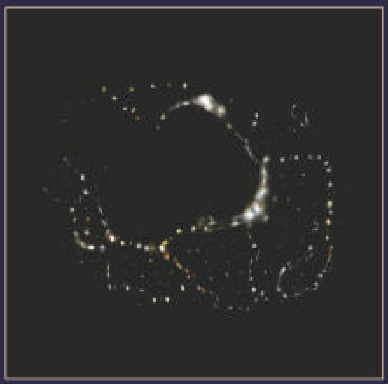
OTHER VOIDS IN THE UNIVERSE

KBC Void

At 2 billion light years in diameter, this colossal expanse is the largest void in the observable universe, representing 2.7 per cent of its size.



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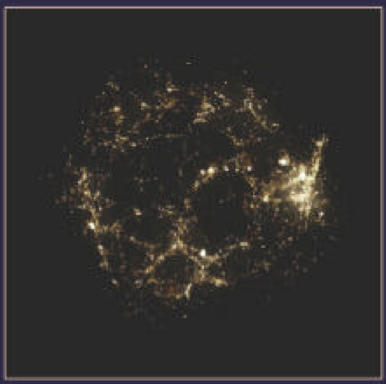
Giant Void

It's 1.3 billion light years in diameter. The Giant Void lies 1.5 billion light years away in the constellation of Canes Venatici, but contains 17 galaxy clusters.



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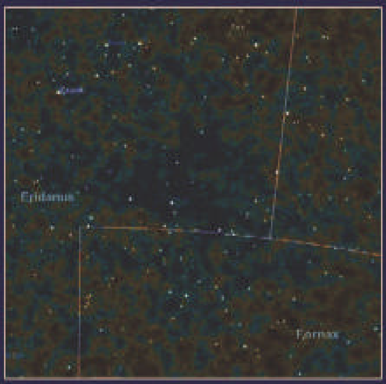
Eridanus Supervoid

An unconfirmed supervoid up to a billion light years in size, the supervoid tries to explain the existence of the 'CMB cold spot', an unusually cold area in CMB data.



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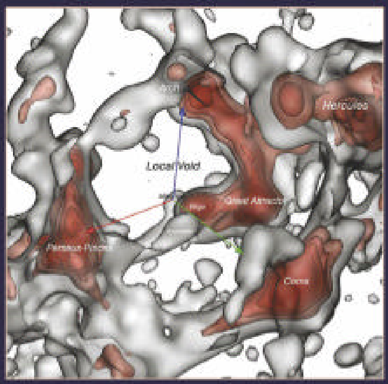
Local Void

Adjacent to the Local Group of galaxies – to which the Milky Way belongs – is the Local Void, whose size is unclear. It's at least 150 million light years in diameter.



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Southern Local Supervoid

Next to the Virgo Supercluster is the 365 million light year-wide Southern Local Supervoid. Its centre lies 313 million light years away.

Source: Wikipedia commons © Pablo Carlos Budassi

was strongest in the interior, where there are very few galaxies compared to a cosmic mean density". This signal then progressively faded towards the edges before changing in areas where there were high galaxy densities. "A positive lensing effect is expected in a surrounding ring where galaxies evacuated from voids reside. These characteristic features in the lensing profile helped us to estimate the amplitude and shape of the signal from DES data in comparison to simulations," they wrote.

What does this result tell us about void environments? Here the differences between dark matter and dark energy become important. Dark matter, an invisible form of mass whose nature is as yet unknown, is only detectable via its gravity and clumps around galaxy clusters. The even more mysterious dark energy accelerates the universe's expansion, but doesn't clump. This, says Kovács, is the key advantage of voids. "The [LCDM] model of dark energy is completely featureless in space and also does not change with time." This mirrors Sutter's comments about voids being the best place to observe dark energy directly due to the paucity of both dark and visible matter inside.

There was another reason for the study, as Vielzeuf and Kovács explain: "A key motivation for our DES analysis was that the largest cosmic voids have shown stronger-than-expected imprints in CMB temperature maps, which challenges the standard cosmological model and may indicate the need for alternative explanations." Some of these alternatives may include modified gravity models. As they point out, the data for their latest study doesn't show this, but still hints at some mystery. "The lensing signals we measured were consistent with the Standard Model, which narrows down the sources of the anomalous imprints, but does not explain them."

Further work is required. "More data is necessary to accurately study different subsets of voids by radius, or understanding the possible evolution of the lensing signal with redshift. To this end, we continue working with the DES team to analyse a new dataset," say the pair. They have a PhD student working with them on these analyses, using three times as much data as before and comparing different possible definitions of cosmic voids. "They are part of the Euclid Consortium and participate in modelling the expected lensing signals from more distant voids." Euclid, scheduled for launch in 2022, is a space-borne ESA spacecraft designed to study the expansion of the universe.

Could such techniques be applied to voids like Boötes? Here the pair are cautious. "While there is growing interest in investigating the lensing effect of deep voids as well as dense clusters, such measurements are truly challenging due to the significant noise levels." For their analysis their team used hundreds of voids to statistically analyse the CMB lensing maps, and a strong signal eventually emerged. vv

A study of Boötes would have to include a large set of Northern Hemisphere voids, something that's almost certain to happen in the future. Sutter, Weygaert and others plan follow-up work with the Vera Rubin Telescope, Euclid, NASA's Nancy Grace Roman Space Telescope, due for launch in 2025, and the Square Kilometre Array. As Sutter says: "There's a lot more to learn about voids!"

HOW DO COSMIC SUPERVOIDS PROVE THAT DARK ENERGY EXISTS?

AR SCAN HERE

Left: Boötes is one of the largest and best known cosmic voids

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Kulvinder Singh Chadha
Space science writer
Kulvinder is a freelance science writer, outreach worker and former assistant editor of *Astronomy Now*. He holds a degree in astrophysics.

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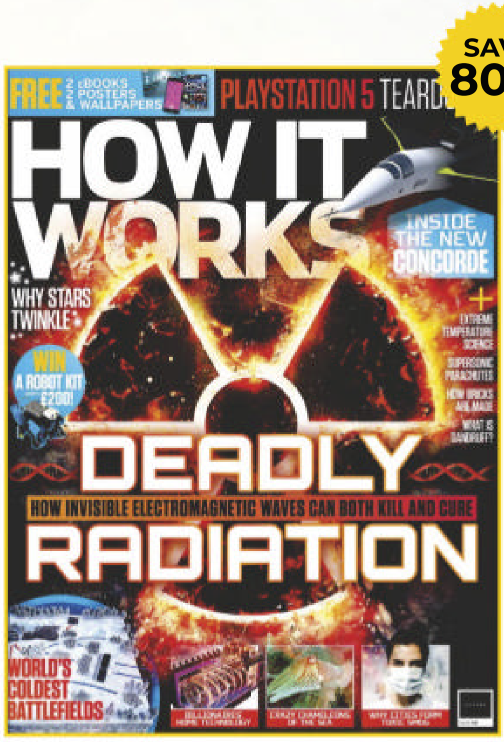

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ALDRIN'S CASTLE

Travelling to Mars could be dangerous and uncomfortable, but Apollo 11 astronaut Buzz Aldrin has a plan to do it in style

When Apollo 11 landed on the Moon in 1969, many at NASA felt there was a good chance they'd be landing astronauts on Mars by 1984. But government priorities changed, and the only part of NASA's grand exploration plan to come to fruition was the Space Shuttle, which taxied astronauts to the International Space Station and no further. Both George H. W. Bush and George W. Bush tried to recapture the spirit, pitching missions to the Red Planet that would have arrived in 2018, but these never became a reality.

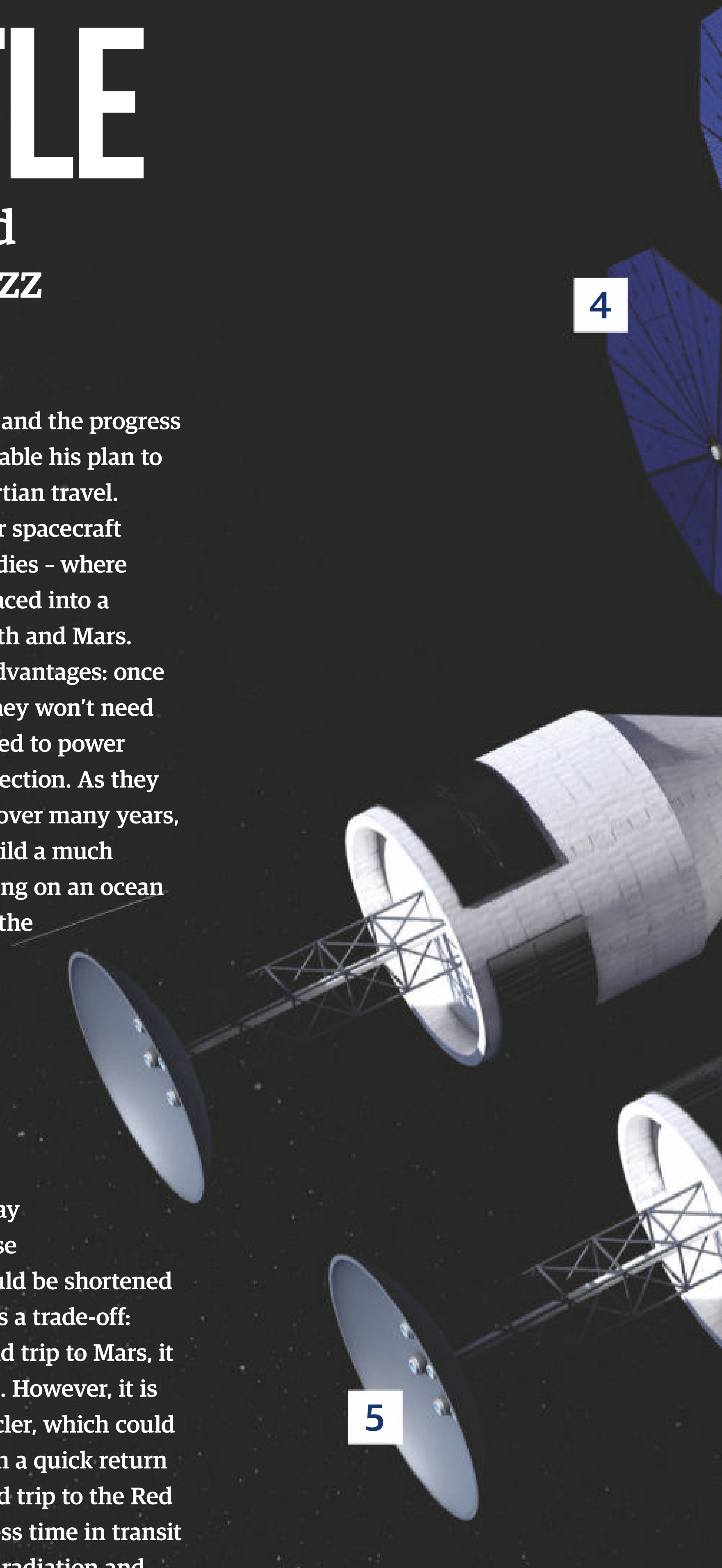
All of these plans and expectations floundered as budgets were cut, and the long build-up for a Mars mission struggled to maintain government support. Now at last the fourth rock from the Sun feels within reach, with NASA working hard on a return to the Moon and a Mars landing in the 2030s with the help of European Space Agency (ESA) participation. And with SpaceX's extraordinary progress on its Starship craft that's looking likely to beat NASA, humankind could arrive on Martian soil during the 2020s.

Both NASA and SpaceX's plans are based on a conventional mission where an exploration spacecraft is put into Earth orbit and serviced in some way - whether assembly or refuelling. From here it boosts off on a minimum-energy trajectory called a Hohmann transfer, an elliptical orbit that boosts out from that of Earth's orbit, coasting outwards until it just touches Mars' orbit on the opposite side of the Sun from where it left our planet. When reaching Mars' orbit, the spacecraft will make a manoeuvre to swing around the Red Planet before either detaching a lander or landing itself. Hohmann transfers use the least energy, so can get as much as possible to Mars for the least money and propellant, but take around six months to get there.

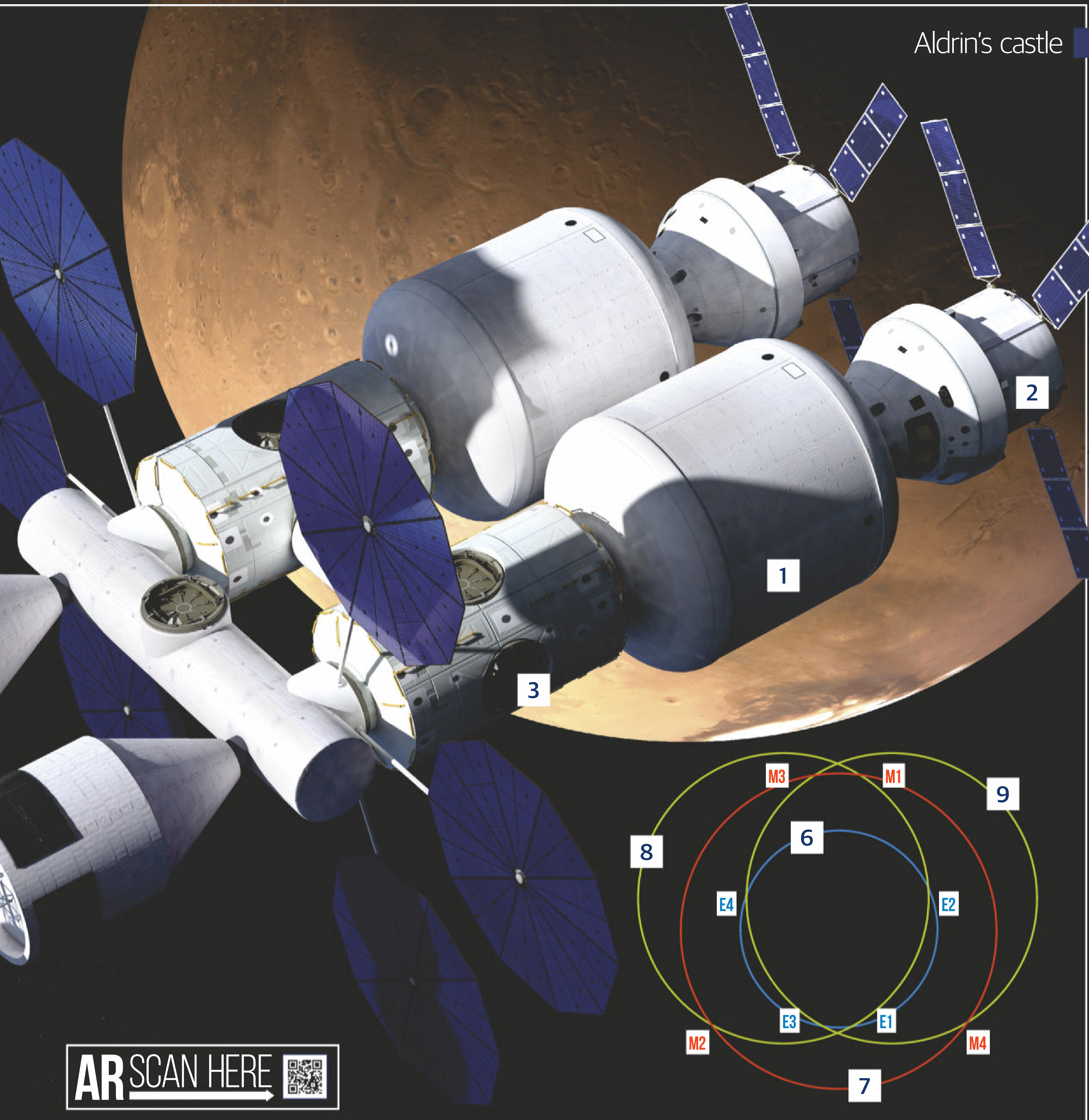
If we're depending upon boosting our entire spacecraft on this trajectory, everything must be reduced to the minimum - even with SpaceX's ambitious plans with Starship - leading to small living spaces, spending months relatively unprotected from the interplanetary radiation environment and no gravity. However, astronaut Buzz Aldrin has been advocating for another route to Mars since the 1980s, and the progress by NASA and SpaceX could enable his plan to provide more comfortable Martian travel.

Aldrin has proposed a cycler spacecraft - nicknamed castles in his studies - where a travelling space habitat is placed into a reoccurring orbit between Earth and Mars. Aldrin's castles offer several advantages: once placed into the cycling orbit they won't need more fuel beyond what's needed to power small thrusters for course correction. As they can be used for multiple trips over many years, it becomes cost effective to build a much larger structure. Akin to hopping on an ocean liner rather than a jet aircraft, the castles could also have greater space, better radiation shielding and the possibility of spin-induced gravity. These liners would actually get you to Mars faster; the cycler orbit can be configured in such a way that a trip that would otherwise take roughly nine months would be shortened to a little over four. But there is a trade-off: while there is a faster outbound trip to Mars, it takes longer to return to Earth. However, it is possible to install a second cycler, which could be placed in a mirror orbit with a quick return to Earth and a longer outbound trip to the Red Planet. Travellers can spend less time in transit while better protected against radiation and microgravity, with cargo taking the spare space on the more lengthy journeys.

The concept does have other challenges, though. One is that the castles never enter orbit around Earth or Mars. Crew would take taxi craft to meet with the castle as it swings by at speeds of 24,000 or 35,000 kilometres (14,900 or 21,750 miles) per hour at Earth and Mars respectively. While the first missions are likely to be self-contained, as the human presence on Mars becomes established and NASA and SpaceX's capabilities develop, Aldrin's castles may well become a bridge to Mars - and one that's possibly comprised of SpaceX Starships.



"ASTRONAUT BUZZ ALDRIN HAS BEEN ADVOCATING FOR ANOTHER ROUTE TO MARS SINCE THE 1980S"



AR SCAN HERE

1 DEEP-SPACE HABITAT

In this concept, the living accommodation is a large, inflatable module like those developed by Bigelow Aerospace.

2 CREW TRANSFER VEHICLES

These craft would meet the cycler in Earth orbit and dock on for the ride to Mars before separating to decelerate into Martian orbit.

3 STRUCTURAL NODE

The cyclers would be built on nodes that joined modules together. This version wouldn't have spin gravity, but future craft might.

4 SOLAR POWER

Inner Solar System missions can exploit plentiful solar power and avoid the challenges of nuclear power.

5 SOLAR ELECTRIC PROPULSION

Variations in planetary orbits mean the cyclers will need some propulsion for course corrections.

6 EARTH ORBIT

Taxi spacecraft would rendezvous with the cycler as it swung past at 24,000 kilometres (14,900 miles) per hour.

7 TO MARS

The cycler coasts back out into interplanetary space, taking four to five months to reach Mars.

8 OUTBOUND CYCLER ORBIT

After the fast transit to Mars, the outbound cycler swings out past Mars, taking a long loop back to Earth.

9 RETURN ORBIT

Rather than having to make a long trip back, a second cycler could be placed in a matching orbit with a quick return path.

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INTERVIEW

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BIO

Dr Abraham Loeb

Loeb is a theoretical physicist and the Frank B. Baird Jr. professor of science at Harvard University, where he is also director of the Black Hole Initiative and the Institute for Theory and Computation. Loeb is the author of five books and 800 scientific papers. In 2012 *Time* selected him as one of the 25 most influential people in space. His most recent book *Extraterrestrial: The First Sign of Intelligent Life Beyond Earth* has caused quite the stir in the scientific community.

DR AVI LOEB

"'OUMUAMUA MAY HAVE AN ARTIFICIAL ORIGIN"

A Harvard astrophysicist shaking things up in the scientific community, Avi Loeb speaks to **All About Space** about his views on extraterrestrial intelligence and the search for life beyond Earth

Interviewed by Daisy Dobrijevic

What do you think 'Oumuamua is?

It was the first object from outside the Solar System that we spotted nearby. It's like finding an object in your backyard from the street. Then instead of you making the trip to the street you can figure out what's in the street from looking at this object, so by that alone it's intriguing.

Most astronomers thought that it must be a comet. However, it didn't show a cometary tail. The Spitzer Space Telescope also searched very deeply around it, and couldn't detect any carbon-based molecules or dust, so clearly it's not a comet. It also didn't behave like an asteroid; it was pushed away from the Sun with an additional force that declined inversely with distance squared smoothly. Usually we get that from the evaporation of an object through the rocket effect - from cometary gases pushing it. However, there were no cometary gases.

The only interpretation I could give to it was reflection of sunlight, but for that it needed to be very thin. The best model was that of a pancake-shaped object. I suggested maybe it's a lightsail, but nature doesn't make lightsails, so it must be artificial in that case.

A few months ago, in September 2020, there was another object detected which also exhibited the push away from the Sun by reflecting sunlight and didn't have a cometary tail. It was given the name 2020 SO, and was traced to be a rocket booster that was launched in 1966. That's the fundamental question: is 'Oumuamua natural, or is it artificial? I'm still arguing that an artificial origin is a viable possibility that we should explore accordingly.

Do you think controversy drives discovery?

Yes. If there is something new that we haven't thought about, that takes us away from preconceptions, from prejudice, obviously it will be controversial. However, you would expect scientists to be open-minded and entertain possibilities that do not match what they were thinking about before - unfortunately that's not the case.

My colleagues tend to say that extraordinary claims require extraordinary evidence, but I claim that extraordinary conservatism leads to extraordinary ignorance.

Did you expect such a buzz from your new book?

No, it went well beyond my expectations by an order of magnitude. I've had about 250 interviews, and there were more than 20 filmmakers and producers from Hollywood that contacted us with interest in the book. Can you believe it?

It's clear from this that the public was starved on the subject for a very long time by the scientific community. The fact that they see a scientist openly discussing it, and there is this object that potentially could be of interest, opens a new window into the search.

My main motivation was putting this question - are we the smartest kid on the block? - on the table. I think it's extremely important for humanity, because it could make us modest. If we realise that we are not the smartest, it will give us a better perspective about our place in the universe, religious beliefs and so forth. I don't think there

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Left: Very deep combined image of 'Oumuamua (circled)

is any other scientific question that has more impact than that, and at the same time it has been completely ignored, that's the amazing thing.

Do you think your appreciation of philosophy has given you a unique perspective on science?
Definitely, but there is also the fact that I grew up on a farm. I used to collect eggs every afternoon, and drive a tractor to the hills of the village on weekends and read philosophy books. That connected me to nature much more than to people. I was not a social animal. I wasn't going to parties like the city people used to do. I think independently, and that you can trace to the farm.

When I see people saying 'it's a rock, it's definitely a rock, I don't care', I want to understand. Does it make sense to say it's a rock or not? Scientists, they become world experts, and that was the advice I was given, to become a world expert in one narrow thing. But I refused to do that, because I enjoyed the bigger reach.

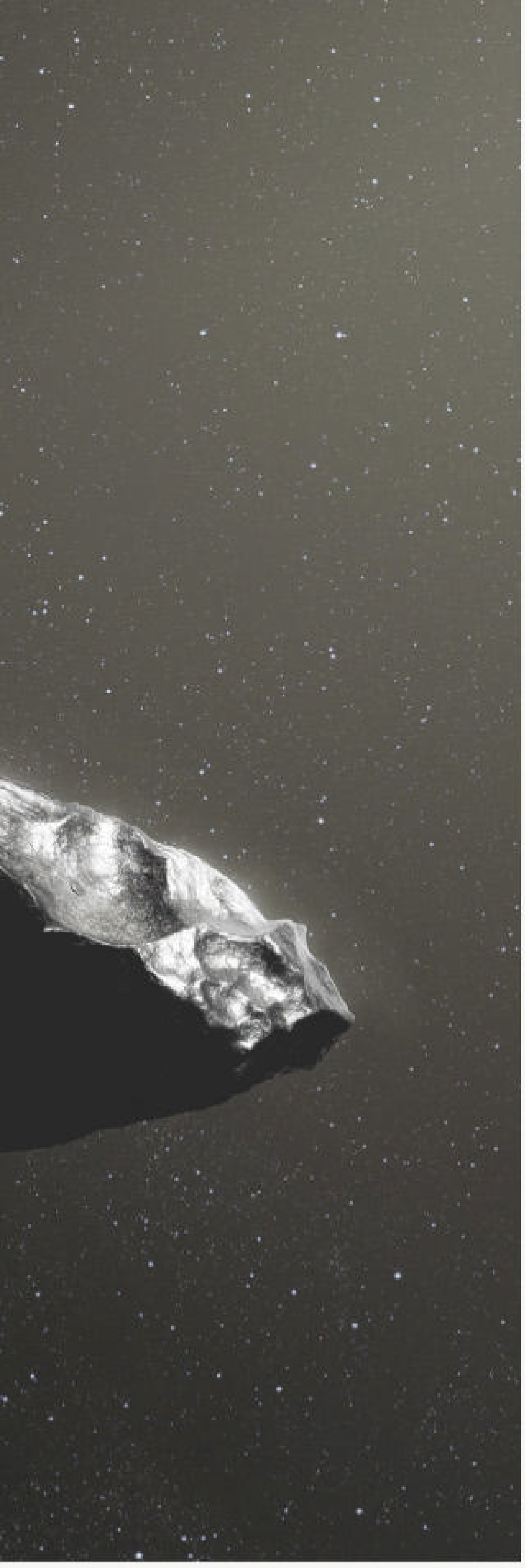
You haven't always been involved in extraterrestrial research. What inspired you to take this particular path?
In 2007 I wrote a paper about searching for radio signals, eavesdropping on other civilisations, because I was working in cosmology. There was a new frontier that I helped pioneer, which was to build radio observatories that will search for the faint radiation from hydrogen in the early universe at very low radio frequencies.

The main obstacle was interference from radio and TV transmissions on Earth. I thought, oh, if it's a problem for us on Earth, maybe we can eavesdrop on other civilisations.

Then in 2012 I visited Abu Dhabi, and the tour guide was bragging that the city lights are seen all the way to the Moon. I was wondering how far away can we see a city with the Hubble Space Telescope. It turns out that you can see it all the way to Pluto. If there was a city like Tokyo on Pluto, we would see it with the Hubble Space Telescope. That was my second encounter, the possibility of searching for artificial light.

In 2015 I wrote a paper about industrial pollution. An undergraduate came to me and wanted to work on something. I said, why don't we check if industrial pollution can be detected? 'Oumuamua showed up in 2017, and that's the trigger that lifted the boat. So yes, only over the past four years have I been really entrenched in this stuff.

When we search for extraterrestrial intelligence, what exactly are we looking for?
In the past 70 years or so we were looking for radio signals, but the problem with that approach is that it requires the counterpart to be alive. That limits the number of civilisations you can learn about. However, if you're looking for relics that are



Left: An artist's impression of 'Oumuamua

© ESO

> EVERY TIME WE THOUGHT THAT WE WERE PRIVILEGED AND SPECIAL, WE WERE PROVEN WRONG IN THE PAST

left behind, then in principle you can see all of them. We can't have a telephone conversation with the Mayan culture, it's not around anymore. But we can look for the relics that they left behind in archaeological sites. The Sun is a latecomer; most stars formed billions of years before the Sun. Other civilisations may have perished billions of years ago, and the only way you'll find them is to look for relics that they left behind.

There are other technosignatures that we look for, but those are remote and over large distances. The advantage of debris or space junk is that, in principle, you can put your hands on it if you land on such a thing. Or if such a thing enters Earth's atmosphere and lands as a meteorite on the ground, then you can study what technology is there and maybe import it to Earth. That could save us a million or a billion years in our own technological development; it could be worth a lot of money.

There are other ways to do it remotely. For example, looking for industrial pollution in the atmospheres of planets around other stars, or looking for photovoltaic cells that cover the dayside or artificial lights on the nightside of planets or looking for structures such as a Dyson sphere or swarm of satellites.

There are lots of different ways, and our imagination is limited by the technologies that we develop. As we develop more and more, we'll have more to search for, because that will expand our imagination. But the archaeology part I think is already here, it's something we should do.

Do you think we should be focusing our resources on studying relics and space archeology rather than searching for signals?
I would definitely do that. In principle this approach allows you to put your hands on a physical object, and there is no substitute for that. Even if you detect a faint signal, the amount of information you have is very limited. If you have an archaeological object, there is a huge amount of information in it. You can maybe read the label and see where it came from. And of course it took these objects millions or billions of years to arrive at our doorstep, so it saves us the trip.

Why do you think we are so obsessed with the possibility of extraterrestrial life?
You can, in principle, be happy just eating good food and having the company of good friends, but to me that, well, that resembles what the dinosaurs used to do. They used to enjoy eating grass, and that was all fine until 66 million years ago, when a giant rock showed up the size of Manhattan Island, and the fun stopped when it hit the ground. You can ignore the sky most of the time, but every now and then it comes to haunt you.

I think the fascination is because it could be something really shocking. When you go out to meet someone, it's a good assumption that this person that you will meet shares qualities with you because you share the same genetic heritage from the distant past. But when you meet life from another planet that has had no contact with Earth whatsoever, it could be completely different. I think there is some fascination about the horror of meeting something totally different. It would shake our core beliefs, like how important we are and religious beliefs. If you look at most religions they focus on us, they don't focus on the possibility that there could be others.

Maybe it's better not to know what's out there...
Scientific knowledge is always good, you can then decide what to do with it. If you are not prepared, if you don't know reality well enough, you're just ignorant. Maybe there are predators out there in space... we want to know about it in advance.

Do you think we're alone in the universe?
No. We're so insignificant relative to the cosmos in many ways, both in terms of size and number of planets. We live for such a short time. We're put on this stage without a script; nobody told us what it's all about. I think we should act in modesty instead of claiming ownership of the stage or claiming arrogance. We should try to figure out what this stage is all about by looking at the universe and looking at how unusual it is.

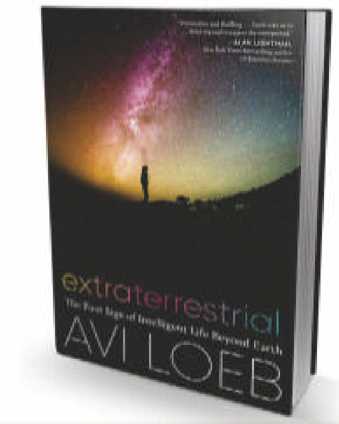
Every time we thought that we were privileged and special, we were proven wrong in the past. So why not learn the lesson for once and for all and just try to figure out what's going on around you? Rather than saying it's never aliens, or it's always rocks and give me extraordinary evidence, what's the big deal? Why is that threatening the egos of so many people? I don't understand that.

We developed our technology only 100 years ago - that's a tiny window of opportunity. In the distant past we were not interesting, so Fermi's paradox, to me, is not really a paradox. It's possible that advanced civilisations don't really want to have contact with us because they have everything they need. They don't want to lower the quality of life by interacting with lower levels.

But that doesn't mean that we can never find out anything about them, because they still have to throw out the trash. We could be just like those investigative journalists that go through the trash cans of celebrities in Hollywood trying to find secrets of their private life.

Extraterrestrial

Loeb is the author of the controversial *Extraterrestrial: The First Sign of Intelligent Life Beyond Earth*, which is now available from all good bookshops and online retailers.



CITIZEN SCIENCE PROJECTS TO TRY AT HOME

HOW YOU CAN GET INVOLVED

If you are interested in becoming a citizen scientist there are a variety of projects that you can get involved in – depending on how 'hands-on' you want to be

From classifying galaxies to identifying features on the Red Planet, **All About Space** reveals how you can contribute to science

Written by Daisy Dobrijevic

© Getty

Citizen science is a great way to gather and analyse large amounts of data with the aid of the general public. Collaboration between scientists and citizens has played an important role across scientific disciplines, especially in regards to space science. You don't need to have any prior knowledge to be a citizen scientist, just a willingness to participate and a desire to aid scientific discovery.

One of the most notable citizen science projects in the history of space science was Operation Moonwatch. Established in 1956 as part of the International Geophysical Year (IGY), it was the brainchild of Fred Whipple, director of the Smithsonian Astrophysical Observatory. The IGY was a worldwide effort to study Earth and its planetary environment, lasting from 1 July 1957 to 31 December 1958.

Many were sceptical about non-experts conducting research, but Operation Moonwatch soon became one of the most successful and long-running citizen science programs in history. The plan was that teams of observers around the world would track, time and document satellites passing over their location. The data would then be fed back to the computation centre and used to position Baker-Nunn cameras around the world, designed to keep an eye on low-Earth orbit (LEO) satellites.

On 4 October 1957, the launch of Sputnik 1 caught the world by surprise. Although the worldwide network of cameras wasn't ready, the thousands of Operation Moonwatch volunteers were. Suddenly the spotlight was on citizen scientists, who were the first to observe and record the trajectory of Sputnik.

Operation Moonwatch continued to play an important role in tracking and documenting satellites Sputnik and Explorer 1. After the IGY ended, teams maintained their patrol of the skies, and in September 1962 were able to provide vital information on the re-entry of Sputnik 4, which had failed to return to Earth two years earlier. Though Operation Moonwatch was disbanded in 1975, many teams continued to observe the skies, and satellite tracking is still a popular pastime for many amateur astronomers around the world. Operation Moonwatch paved the way for modern-day citizen science, having highlighted the value of collaborative research between the general public and scientists. Nowadays participation in citizen science projects couldn't be more straightforward, with many easily accessible from home on your computer or even an app on your mobile phone.

LEVEL 1 LOW-INPUT PROJECTS

If you don't have that much time to dedicate to citizen science, but you still want to contribute to scientific research, then these projects are the ones for you. The only time you really need to devote to them is the initial set up. After that you can simply sit back, relax and let your computer do all the hard work for you. Who knew contributing to scientific discoveries could be so easy?

BOINC PROJECTS

BOINC.BERKELEY.EDU

One of the most popular platforms for 'hands-off' research is Berkeley Open Infrastructure for Network Computing (BOINC). Here you can view numerous computing projects that span the sciences, taking part in any number of available projects. BOINC simply runs on your computer: once the initial set up is complete, the platform downloads scientific computing jobs and runs them invisibly in the background when connected to the internet. A majority of the projects are available for Windows, Linux and Apple macOS computers, with some also available for Android devices.

Even though you participate in these projects on your own, with your computer doing all the work, the BOINC projects still have a good sense of community. There are news bulletins, message boards and even a 'user of the day' announcement, all of which make you feel like you are part of something special.

SPACE-RELATED BOINC PROJECTS INCLUDE

UNIVERSE@HOME

UNIVERSEATHOME.PL

Sponsor: University of Warsaw

Contribute to the understanding of the universe with Universe@Home, the first project of its kind based in Poland. The current topics investigated by Universe@Home include ultraluminous X-ray sources, gravitational waves and Type Ia supernovae. All of the results from the research are publicly available, and there are currently over 28,000 computers registered on the project.

ASTEROIDS@HOME

ASTEROIDSATHOME.NET

Sponsor: Charles University

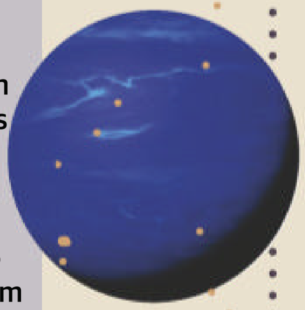
There's a large disparity between the number of asteroids we have discovered and those with known physical properties. Asteroids@home aims to rectify this problem by deriving shape and spin for a significant portion of the known asteroid population. The results not only contribute to our scientific understanding, but are also made available to the public in the DAMIT database.

EINSTEIN@HOME

EINSTEINATHOME.ORG

Sponsor: University of Wisconsin-Milwaukee, Max Planck Institute for Gravitational Physics

With over 500,000 volunteers and counting, Einstein@Home is a big name. It uses your computer's idle time to search for faint astrophysical signals from pulsars. Its main goal is to make the first detections of gravitational-wave emissions from spinning neutron stars.



SETI@HOME

SETIATHOME.BERKELEY.EDU

Sponsor: University of California, Berkeley

SETI@home works to analyse radio telescope data in the Search for Extraterrestrial Intelligence (SETI). This project has been so successful that on 31 March 2020 SETI@home was put into hibernation, as the project has currently analysed all the data researchers need for now. The team behind SETI@home is now completing the back-end analysis of results and writing up scientific papers. You can continue to keep up to date with the progress by visiting the news column on the home page, as well as the message boards.

MILKYWAY@HOME

MILKYWAY.CS.RPI.EDU

Sponsor: Rensselaer Polytechnic Institute

By harnessing the computational power of volunteers, Milkyway@home is busy building a highly accurate three-dimensional model of the Milky Way using data collected from the Sloan Digital Sky Survey.

If you would like to take part in research which requires a little more input from you, but is still not too time consuming, then these are the projects for you.

LEVEL 2 MEDIUM-INPUT PROJECTS

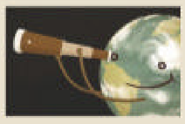
ZOONIVERSE

ZOONIVERSE.ORG

The world's largest platform for citizen science, Zooniverse projects have contributed to new discoveries, accessible datasets and multiple scientific publications. You don't need to have any specialist knowledge to take part, as each Zooniverse project gives you a brief introduction to the research area and clear step-by-step instructions for the task at hand. The projects are designed to be accessible to all, with ample opportunities to ask for help and discuss the projects with other volunteers around the world.

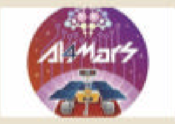
Zooniverse projects span many research areas, from sociology to biology and languages to the arts. With each project, you can see how many volunteers are involved and how complete the project is. There are also mobile-friendly projects that can be completed on the Zooniverse app, available for Android and Apple devices.

BACKYARD WORLDS: PLANET 9



Using data from NASA's Wide-field Infrared Survey Explorer (WISE), this searches the realm beyond Neptune for new brown dwarfs and planets to gain a better understanding of how both stars and planets form. The project is also on the hunt for the elusive Planet Nine, whose presence has been suggested by models and may have already been imaged with NASA's WISE telescope. Though we are yet to observe Planet Nine, eagle-eyed participants in the project are keeping their eyes peeled.

AI4MARS

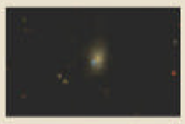


Knowing how to effectively navigate the Martian terrain is crucial for exploration missions. NASA's Spirit got stuck in a sand trap, ending its seven-year mission. Opportunity and Curiosity also experienced sand-related issues. Opportunity was able to navigate itself out of the sand, and Curiosity changed course before succumbing to a similar fate. In this Zooniverse project, you can help future Martian rovers navigate the terrain more effectively and avoid potentially dangerous situations by labelling images from Curiosity, helping to create the first open-source navigation-classification dataset of Mars.

STAR NOTES

This novel project involves transcribing the notes of early female astronomers. The notebooks of these astronomers and Harvard Computers have been digitised, and the aim of Star Notes is to link these notebooks back to the original source material, 500,000 glass-plate photographs which represent the first-ever pictures of the visible universe.

ZWICKY CHEMICAL FACTORY



Spectroscopy is used to understand the chemical composition of supernovae, shedding light on what type of star exploded. You can help classify these explosions by comparing spectral data against known reference data and assessing the fit. The project involves comparing your spectral line against five potential matches and choosing which (if any) are the closest match.

STARDUST@HOME

STARDUSTATHOME.SSL.BERKELEY.EDU

Join fellow volunteers in the hunt for interstellar dust particles embedded in aerogel that were collected and brought back to Earth aboard NASA's Stardust spacecraft. You need a sharp eye for this project as the dust particles are only about a micron in size, and the collector plates are littered with numerous flaws, cracks and uneven surfaces.

AURORASAURUS

AURORASAURUS.ORG

If you're lucky enough to live in a part of the world where aurora sightings are possible, this project is perfect for you. Aurorasaurus allows participants to log aurora sightings via the submission of a report on the website or by sending a tweet on Twitter. Along with contributing to scientific understanding of aurorae, participants earn badges.

COSMOQUEST

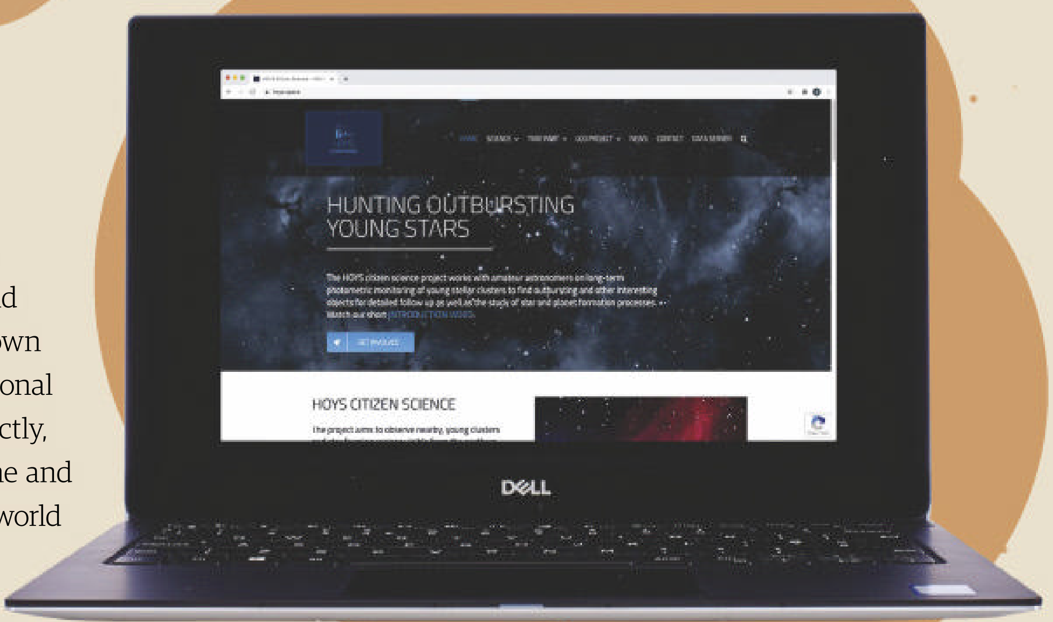
COSMOQUEST.ORG

Projects follow a similar format to Zooniverse, with an introduction into the projects along with step-by-step instructions on how to carry out each task. There are three projects on CosmoQuest: Moon Mappers, Mars Mappers and Mercury Mappers. Though these are currently down for maintenance, they will be back up and running soon.

LEVEL 3 HIGH-INPUT AND MORE SPECIALISED

PRO-AM COLLABORATIONS

When scientists require the help of citizens with more specialist knowledge, they can reach out and partner with amateur astronomers in what is known as a PRO-AM collaboration. While a lot of professional organisations reach out to astronomy groups directly, there are many that advertise opportunities online and welcome amateur astronomers from around the world to participate.



HOYS CITIZEN SCIENCE

HOYS.SPACE

If you are an avid astrophotographer, this may be the project for you. The Hunting Outbursting Young Stars (HOYS) project works with amateur astronomers around the world to hunt and study outbursting young stars, which involves long-term photometric monitoring of young stellar clusters. The project requires images of target objects, most of which are also interesting to photograph - you may even have already captured them. Contributors then upload their images onto the HOYS system and follow further processing steps. There are detailed steps on how to get involved presented on the HOYS website, along with an informative step-by-step video.

AMERICAN ASSOCIATION OF VARIABLE STAR OBSERVERS (AAVSA)

AAVSO.ORG/GET-INVOLVED

This project involves both variable star observations and data mining for those without telescopes. From an observational perspective the project requires contributors to observe and record variable stars from a list of target stars following an in-depth tutorial presented by AAVSA. For those who would rather contribute from the comfort of their own home, there are numerous data-mining projects to get involved with, each with their own aims and objectives.

IMAGE-PROCESSING SITES

JUNOCAM

MISSIONJUNO.SWRI.EDU

Create your very own stunning images of Jupiter by downloading and processing raw images captured by the Juno spacecraft. Here users are encouraged to process images in their own way, from simple cropping and colour enhancements to creating collages and adding advanced colour reconstruction. There is also an online gallery for you to view other users' contributions and upload your own images.

CHANDRA

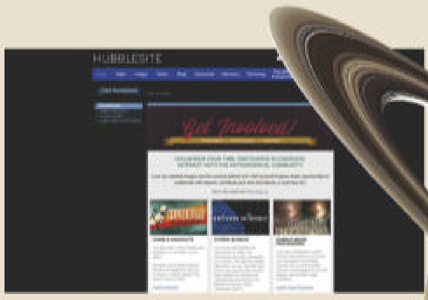
CHANDRA.HARVARD.EDU/PHOTO/OPENFITS

For those of you looking for a little more of a challenge with your image-processing antics, the Chandra X-Ray Observatory may be for you. Here you can create your own images from FITS (Flexible Image Transport System) files of some of the most iconic Chandra images. There are various tutorials to guide you through the image processing, as well as related blog articles.

HUBBLE

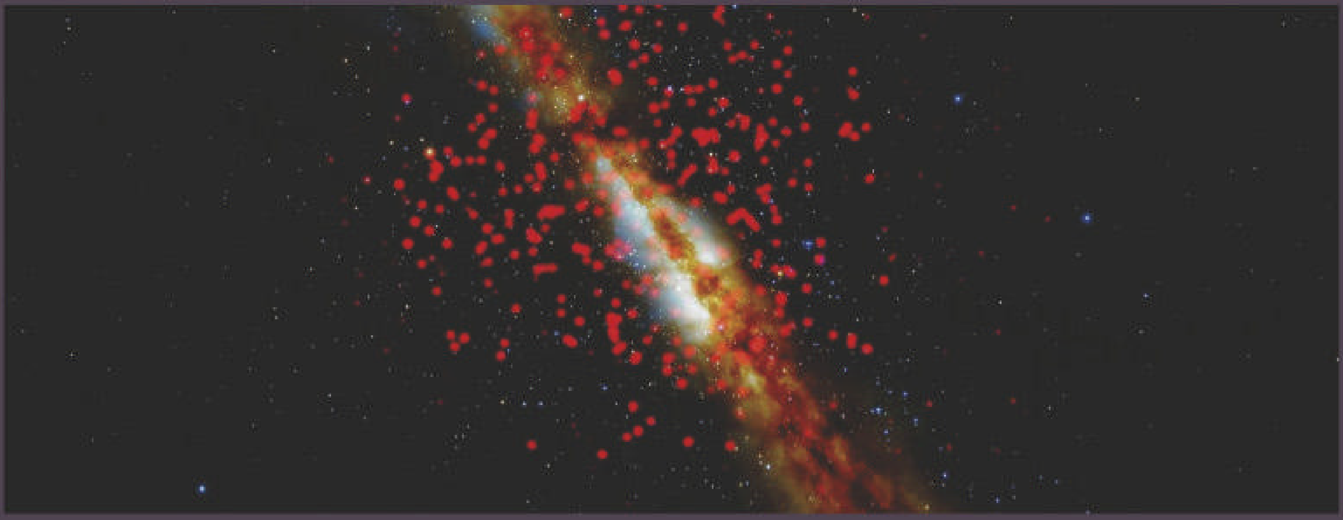
HUBBLE.STSCI.EDU/GET _ INVOLVED

Fancy embarking on a new image-processing adventure? There are many beautiful images waiting to be discovered within datasets that are available to the public in the Hubble archive. Although there are tutorials available, this project is more suited to those with good knowledge of image-processing software and Hubble instruments in order to pick out useful datasets for image reconstruction.



These projects require some existing knowledge, and you may need to work closely with scientists from various institutions in furthering discoveries.

CITIZEN SCIENCE IN THE NEWS



© NOIRLab/NSF/AURA/J. da Silva

Right: 3D map of 525 brown dwarfs in the Sun's neighbourhood, 38 of which were discovered by citizen scientists

CITIZEN SCIENTISTS DISCOVER DOZENS OF BROWN DWARFS NEAR EARTH

Thanks to citizen scientists taking part in the Zooniverse project Backyard Worlds: Planet 9, scientists have been able to produce the most complete 3D map of brown dwarfs neighbouring our Solar System, within 65 light years of the Sun. The map contains 525 brown dwarfs, including 38 that were discovered by the Backyard Worlds: Planet 9 citizen science project.

Brown dwarfs are an oddity. Neither planet nor star, they're tricky to study as they're incredibly faint and relatively small. In addition to the impressive 3D map created, scientists also discovered that cool brown dwarfs are more rare in the Sun's immediate neighbourhood - approximately seven light years - than astronomers previously thought. It is therefore possible that these particular objects are simply too faint to find using existing telescopes. Backyard Worlds: Planet 9 has already proven to be a huge help to scientists studying brown dwarfs, but with the project only 29 per cent complete at the time of writing, there is still plenty of room for more surprises and scientific discoveries. You never know, one lucky citizen scientist may be the first to spot Planet Nine.

EINSTEIN@HOME UNVEILS IDENTITY OF MYSTERIOUS GAMMA-RAY SOURCE

Using data supplied by NASA's Fermi Gamma-ray Space Telescope and the computational power of all those participating in the Einstein@Home project, scientists have revealed a rapidly spinning neutron star is located at the core of a celestial object known as PSR J2039-5617.

The exotic gamma-ray pulsar rotates about 377 times each second and orbits with a star about a sixth the mass of our Sun. This celestial dance is heading for a destructive finale, as the pulsar is slowly evaporating its stellar companion.

These so-called 'spider' binary pulsar systems are given arachnid names such as 'black widows' or 'redbacks' after species of spider where the females are known to kill the males after mating.

For many years a pulsar had been inferred to exist at the heart of PSR J2039–5617, but it was only after the contributions from Einstein@Home participants that a formal identification was possible. The project combed through ten years of archival observations from NASA's Fermi Gamma-ray Space Telescope. Analysing this much data would have taken 500 years on a single computer, but by making use of the Einstein@Home program, analysis was achieved in just two months. This discovery is a prime example of how crucial citizen science is, proving that you can be a valuable piece of the puzzle without really lifting a finger.

© NASA

Left: An artist's impression of a pulsar

Right: STEVE differs in colour from normal aurorae

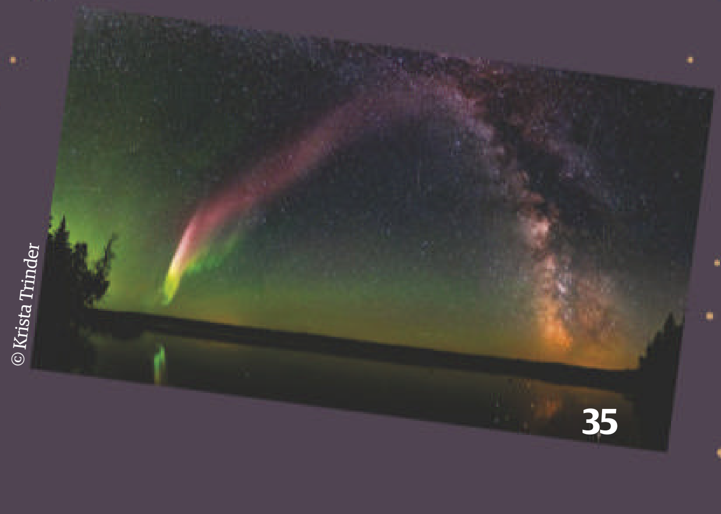
CITIZEN SCIENTISTS' DISCOVERY OF STEVE

Strong Thermal Emission Velocity Enhancement, or STEVE, has been making headlines since the discovery of the aurora-like phenomenon. Though formal research on the discovery was published in 2018, avid photographers and citizen scientists have been photographing STEVE since 2015, reporting 30 instances of the purple-and-green picket fence in the sky.

Though observations had been going on for years, STEVE remained obscure until the citizen science project Aurorasaurus collaborated with citizen scientists and various other researchers to publish the first scientific paper describing the phenomenon.

Citizen scientists are pivotal in STEVE research. Their time-lapse images are usually carried out for longer than scientific observations, therefore building a more in-depth picture of the optical phenomenon. Their contributions don't go unnoticed, with many citizen scientists' names appearing alongside other researchers on published papers.

Scientists currently know very little about STEVE, and while data can suggest if an aurora will be visible, indicators for STEVE have yet to be identified. However, avid aurora chasers always have their cameras at the ready and have a knack for spotting and documenting STEVE before anybody else.



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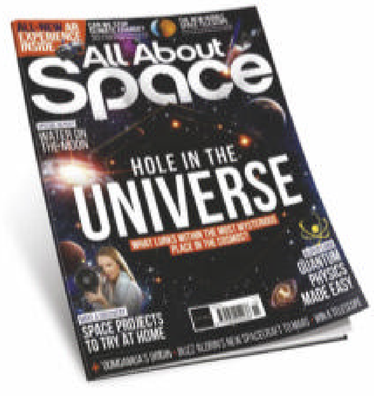

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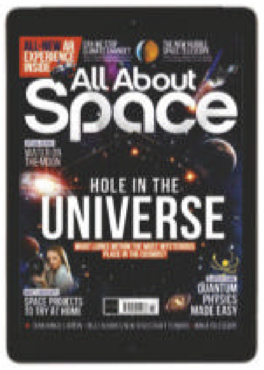

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CAN WE STOP EARTH HEATING UP?

The SCoPEx high-altitude balloon mission will investigate a controversial way to reduce global temperatures

Reported by Andrew May

In 2021, Earth hits a bleak milestone. The concentration of carbon dioxide (CO_2) in the atmosphere will hit 150 per cent of its value in preindustrial times. That excess will be the consequence of human activities, the direct cause of the current climate emergency. If global temperatures are to remain no more than 1.5 degrees Celsius (2.7 degrees Fahrenheit) above preindustrial levels, according to the United Nations' Intergovernmental Panel on Climate Change (IPCC), the world needs to decrease net emissions of CO_2 to zero by 2050.

But even this won't put a sudden brake on the temperature rise, because it takes time for CO_2 reductions to take effect. The negative impacts of global warming will continue for decades to come, but is there anything else we can do to help bring temperatures back down to normal sooner?

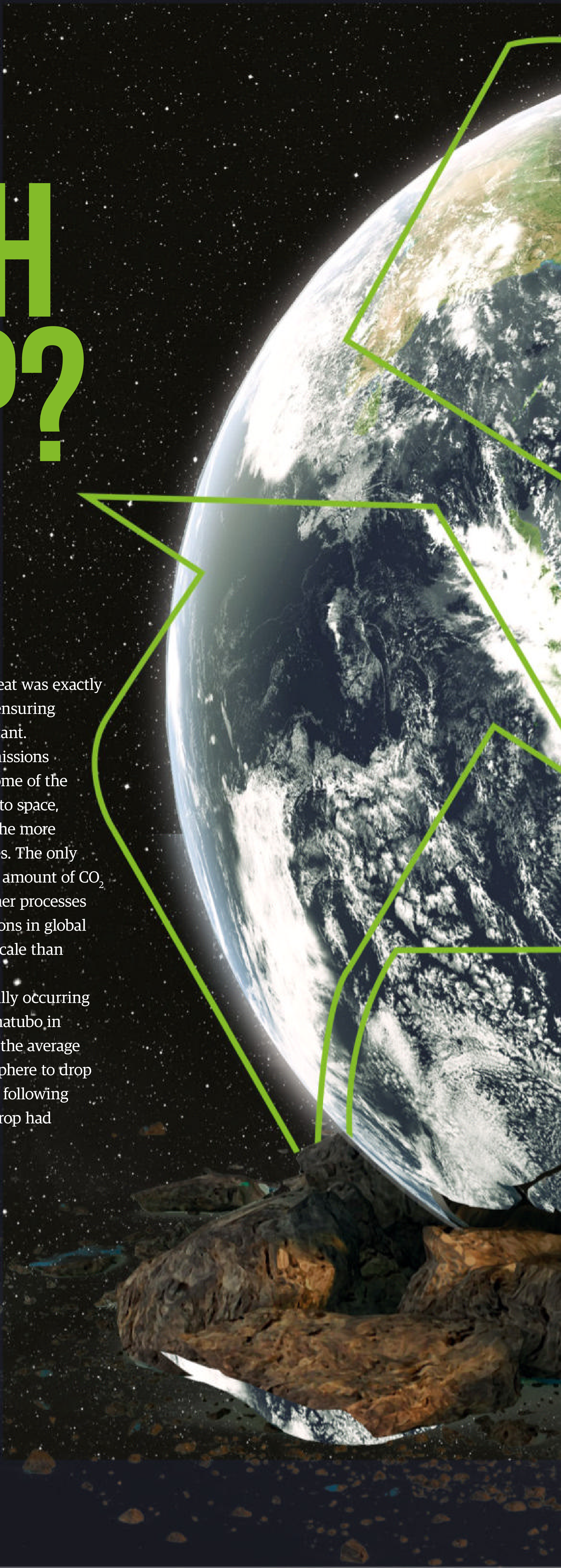
A research group at Harvard thinks it might be possible to achieve a temporary reduction in global temperatures by making small tweaks to the composition of Earth's upper atmosphere. Researchers are hoping to test some of that technology - and the viability of their theory - later this year in what they call the Stratospheric Controlled Perturbation Experiment, or SCoPEx.

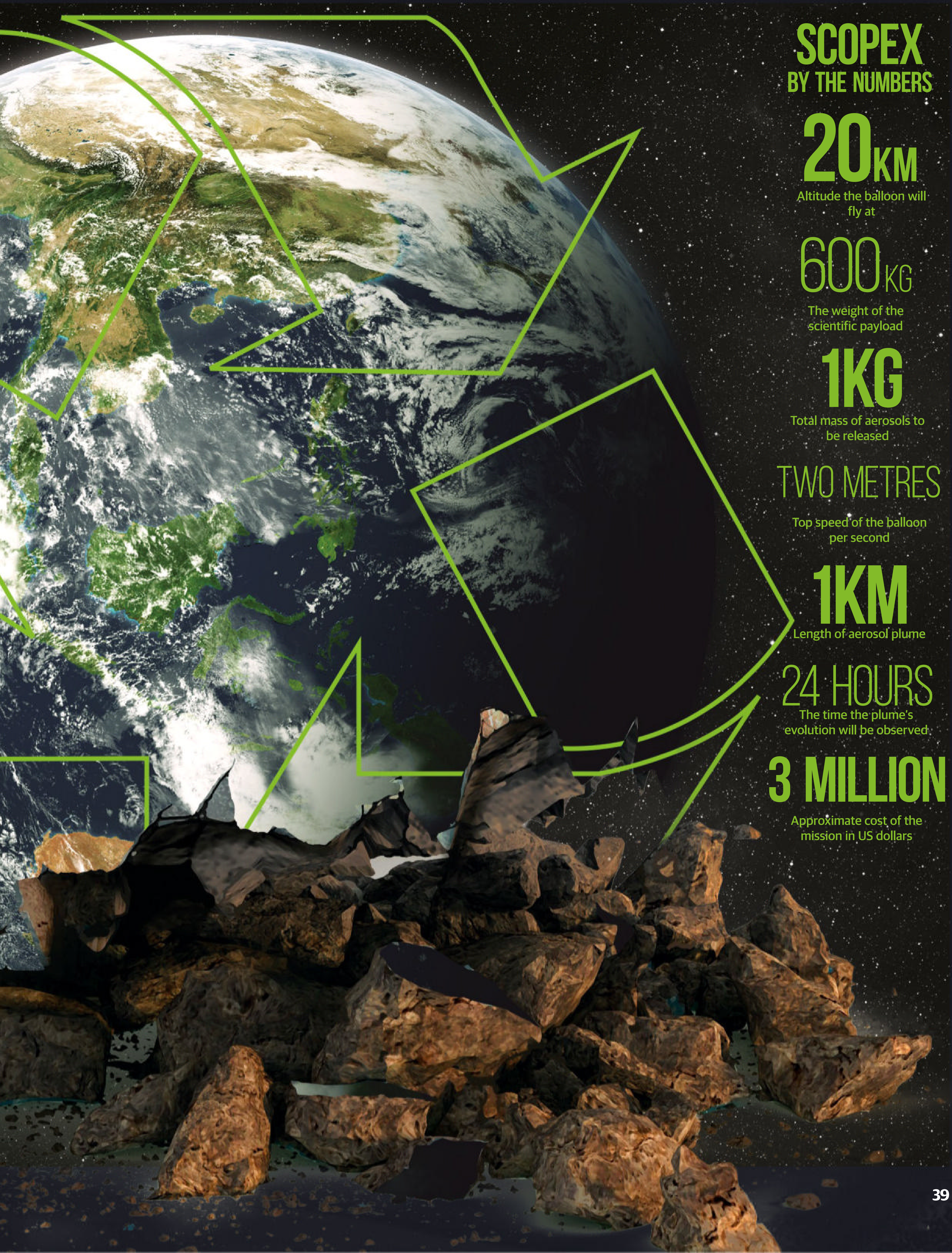
The ultimate source of Earth's heat is the Sun, which bathes the daytime side of the planet in a constant flow of infrared radiation. About 30 per cent of this is reflected back into space by the atmosphere, while the rest of it warms the planet during the day and is reradiated back into space at night. In the delicate balance that prevailed in preindustrial times, the incoming heat was exactly offset by the amount lost to space, ensuring global temperatures remained constant.

The problem today is that CO_2 emissions disrupt this balance by absorbing some of the heat that should be radiated back into space, trapping it inside the atmosphere. The more CO_2, the higher the temperature rises. The only permanent solution is to reduce the amount of CO_2 in the atmosphere. But there are other processes that can produce short-term reductions in global temperature on a much faster timescale than reversing the greenhouse effect.

Volcanic eruptions are one naturally occurring example. The eruption of Mount Pinatubo in the Philippines in June 1991 caused the average temperature in the Northern Hemisphere to drop by more than half a degree over the following 15 months. This sudden, dramatic drop had

> "IN SIMULATIONS, STRATOSPHERIC AEROSOL INJECTION (SAI) APPEARS TO BE A VIABLE CONCEPT"





SCOPEX
BY THE NUMBERS

20KM

Altitude the balloon will fly at

600KG

The weight of the scientific payload

1KG

Total mass of aerosols to be released

TWO METRES

Top speed of the balloon per second

1KM

Length of aerosol plume

24 HOURS

The time the plume's evolution will be observed

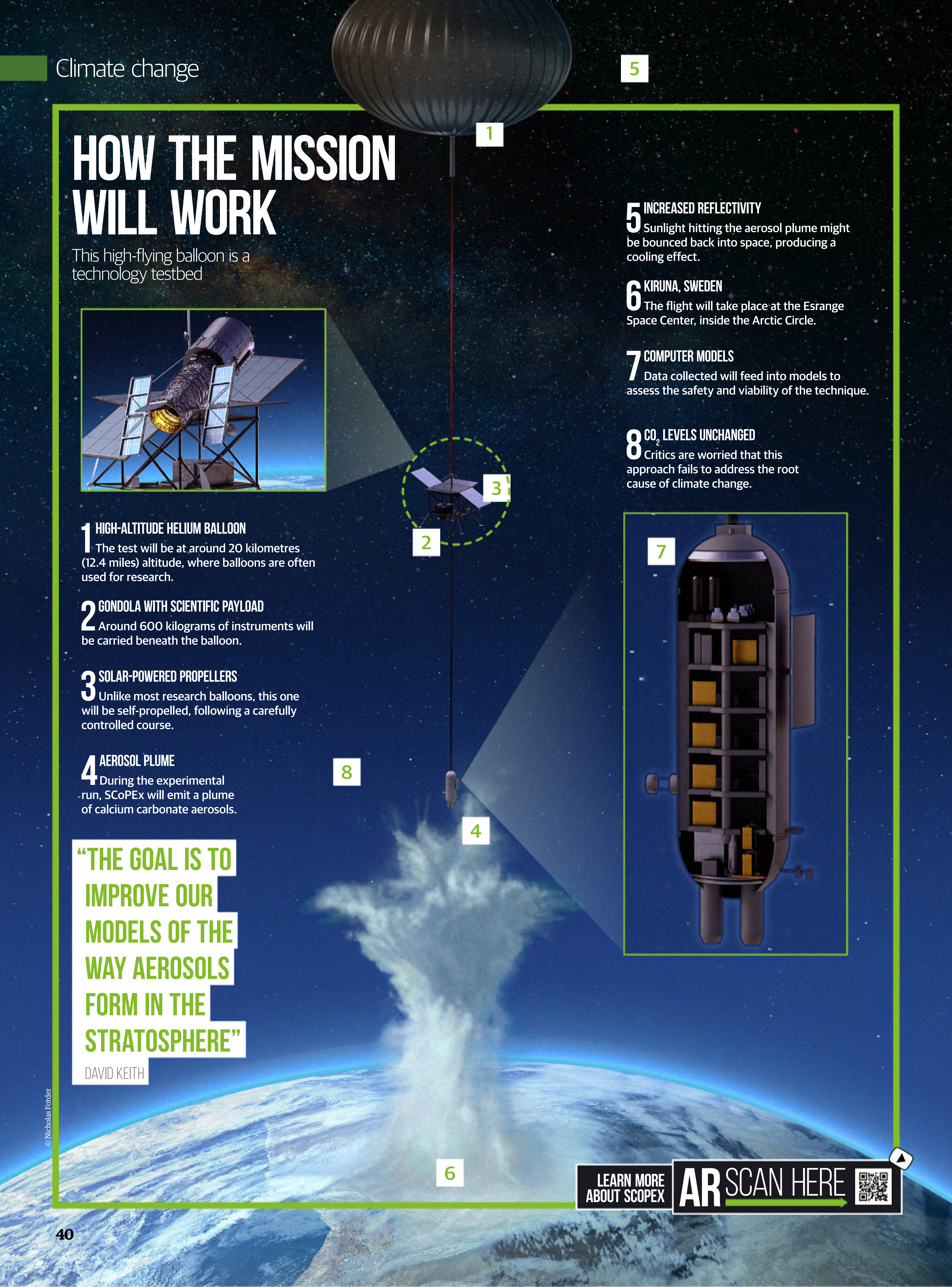
3 MILLION

Approximate cost of the mission in US dollars

© Getty; Tobias Roetsch

HOW THE MISSION WILL WORK

This high-flying balloon is a technology testbed



1 HIGH-ALTITUDE HELIUM BALLOON
The test will be at around 20 kilometres (12.4 miles) altitude, where balloons are often used for research.

2 GONDOLA WITH SCIENTIFIC PAYLOAD
Around 600 kilograms of instruments will be carried beneath the balloon.

3 SOLAR-POWERED PROPELLERS
Unlike most research balloons, this one will be self-propelled, following a carefully controlled course.

4 AEROSOL PLUME
During the experimental run, SCoPEx will emit a plume of calcium carbonate aerosols.

> "THE GOAL IS TO IMPROVE OUR MODELS OF THE WAY AEROSOLS FORM IN THE STRATOSPHERE"
>
> DAVID KEITH

5 INCREASED REFLECTIVITY
Sunlight hitting the aerosol plume might be bounced back into space, producing a cooling effect.

6 KIRUNA, SWEDEN
The flight will take place at the Esrange Space Center, inside the Arctic Circle.

7 COMPUTER MODELS
Data collected will feed into models to assess the safety and viability of the technique.

8 CO_2 LEVELS UNCHANGED
Critics are worried that this approach fails to address the root cause of climate change.

© Nicholas Forder

LEARN MORE ABOUT SCOPEX AR SCAN HERE

© NASA

Above: Balloons, such as this one operated by NASA, are often used for upper-atmosphere research

nothing to do with CO_2 levels or the greenhouse effect, which continued to trap heat inside the atmosphere unabated. Instead there was simply less heat to start with. A volcano blasts a cloud of dust particles high up into the stratosphere, forming a protective shield that prevents a fraction of the Sun's heat from reaching Earth's surface.

Temporarily lowering temperatures by injecting particles into the upper atmosphere is what the SCoPEx team believes we should be using in the fight against climate change. The basic idea is simple. A high-flying aircraft or helium balloon would dispense batches of microscopic particles, referred to as aerosols, into the stratosphere at altitudes of 20 kilometres (12.4 miles) or more - much higher than planes usually fly. The aerosols would remain suspended in the air, too tenuous to be visible from the ground, but enough to reflect a fraction of the Sun's energy back into space.

In simulations, stratospheric aerosol injection (SAI) appears to be a viable concept. In a 2018 report, the IPCC concluded that a fleet of high-flying aircraft could deposit sufficient aerosols to offset current levels of global warming. But it's not a permanent solution - the aerosols would have to be replenished every few years - and it only tackles one of the symptoms of climate change, rather than addressing its root cause, the greenhouse effect. At best it's a stopgap measure, countering rising temperatures while other efforts are made to reduce CO_2 levels.

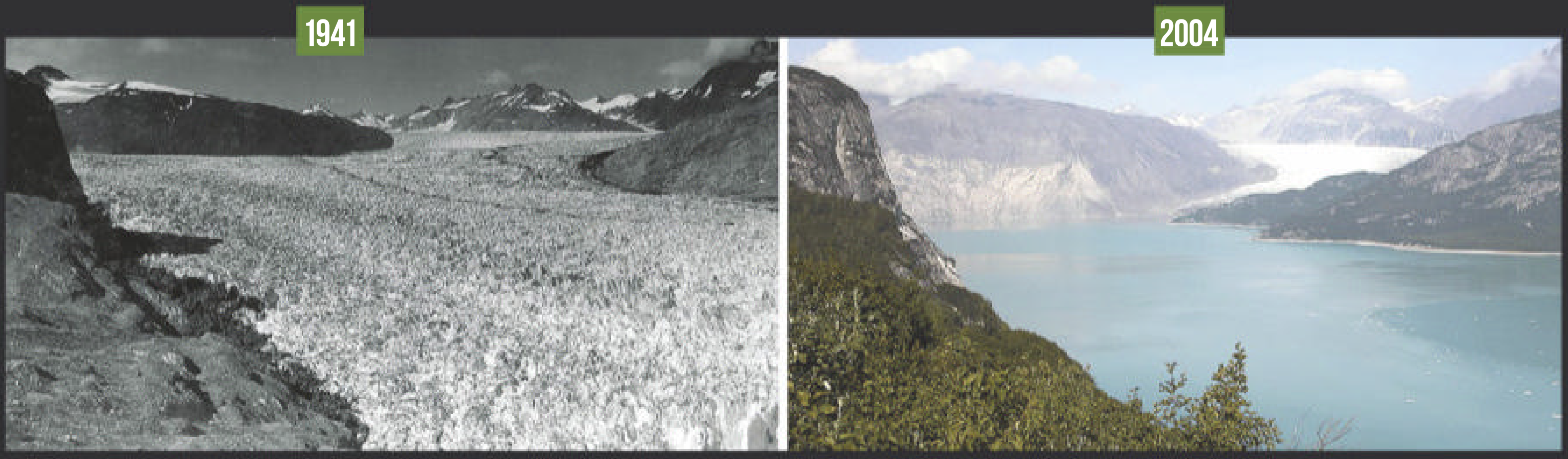
So far the research carried out on SAI has been theoretical, supplemented by a limited amount of real-world data from volcanic eruptions. The aim of SCoPEx is to make further measurements under carefully controlled conditions, allowing better calibration of the computer models. As Frank Keutsch, the project's principal investigator, puts it: "If we are to provide decision-makers with useful information about whether this could work, we need to ground-truth our models."

The natural aerosols ejected by volcanoes are mainly composed of sulphur compounds, but there's a downside to using these in SAI. As well as cooling the atmosphere, sulphides can damage Earth's protective ozone layer, which shields us from harmful UV radiation. For this reason the SCoPEx team is focusing on a more benign aerosol, calcium carbonate - chalk dust, in other words - which researchers hope will produce the desired cooling effect without harming the ozone layer.

SCoPEx will use a large, uncrewed helium balloon, similar to a standard weather balloon except that it is fitted with propellers to allow the team on the ground to manoeuvre it in a controlled way. With assistance from the Swedish Space Corporation, scientists will launch the balloon near Sweden's Kiruna. On its first flight, pencilled in for this summer, no actual material will be released into the stratosphere. The balloon will simply ascend to 20 kilometres (12.4 miles) altitude, where the team will try out the manoeuvring system and check that all the scientific instruments and communications function correctly.

Assuming the test run is successful, a second flight will perform a controlled release of one or two kilograms of calcium carbonate at the same altitude. The idea is that the balloon will be moving steadily in a straight line during the release, so the aerosol particles will form a narrow plume around a kilometre (0.6 miles) in length. The balloon will then turn back through the plume, observing how the particles disperse over time and the extent to which they reflect sunlight.

As valuable as SCoPEx will be for our understanding of SAI, it's important to see the project in perspective. "The goal is not to change



© William Osgood Field (1941) and Bruce F. Molnia (2004), NSIDC

Below: The greenhouse effect is causing less ice to form and glaciers to melt

Q&A WITH THE SCOPEX TEAM

Why conduct the experiment?

Computer modelling and laboratory work tell us some very useful things, but outdoor experiments can provide perspective that is impossible to obtain in the laboratory, and SCoPEx can help us validate important model parameters.

Is it dangerous?

The test will pose no significant hazard to people or the environment. Calcium carbonate is a non-toxic chemical commonly found in nature. The amount of material will be very small compared to other routine releases into the stratosphere by aircraft, rockets or balloon flights.

What is the purpose of the initial test flight?

A platform test is needed before the science experiment because SCoPEx will use a new flight platform that has not flown before. There are significant technical challenges in developing it as an operational vehicle independent of the challenges of the actual experiment.

Why Sweden?

We have chosen to partner with the Swedish Space Corporation because of its availability for summer 2021 and experience launching scientific balloons. We also looked at several US balloon operators, but because of COVID-19 and other logistical and scheduling challenges, there were no US-based options that could provide a 2021 early summer launch.

the climate or even to see if you can reflect any sunlight," one of the project scientists, David Keith, explains. "The goal is simply to improve our models of the way aerosols form in the stratosphere." Keith says that at least another decade of research will be needed before the large-scale implementation of SAI could be contemplated. This, he says, "might involve injecting around 1.5 million tonnes into the stratosphere per year ... roughly a hundred aircraft would need to continuously fly payloads up to about 20 kilometres (12.4 miles) altitude."

Given the daunting amount of work still to be done, it's surprising to learn that SAI isn't a new idea. It's been around since the 1970s, and Keith himself has been working in the area for more than 20 years. But the research has progressed at a snail's pace, partly due to a lack of official funding. A project as ambitious as SCoPEx would have been impossible without funding from private investors. On top of that, there are other issues that have slowed down research and caused repeated delays to the SCoPEx mission itself, which was originally proposed back in 2015.

There are two major controversies associated with SAI. The first is the gut reaction that tampering with nature is a bad idea. We created the climate crisis in the first place by pumping greenhouse gases into the atmosphere, so how can we be sure that pumping aerosols into it will make things better? Although computer modelling has indicated that SAI is safe, there's still the possibility that it might have unforeseen side effects. People have speculated that it could disrupt weather patterns, harm crops by reducing the amount of sunlight they receive and - if sulphide aerosols are used - damage the ozone layer.

Arguments like these have led to a number of scare stories in the media, such as a far-fetched headline in the *Daily Mail* in 2019 that read: Bill Gates wants to spray millions of tonnes of dust into the stratosphere to stop global warming, but critics fear it could trigger calamity. Even some scientists are wary of following the SAI route. "That we might actually try to control the entire climate is a pretty terrifying idea," as Douglas MacMartin, a professor at Cornell University in New York, put it. And the IPCC, in a 2018 discussion of what it refers to as Solar Radiation Modification, or SRM, concluded that "the combined uncertainties, including technological maturity, physical understanding, potential impacts and challenges of governance, constrain the ability to implement SRM in the near future".

But none of this detracts from the need for research. SCoPEx aims to collect data in order to improve our scientific understanding. The real danger would be for some maverick organisation to go ahead with a large-scale implementation of SAI without that kind of scientific understanding. "What would be best," Keith says, "is for countries not to just start doing it, but to articulate clear plans and build in checks and balances".

The second big objection to SAI research is harder to brush away. Rather than any imagined physical danger it might pose, the worry here is that governments and corporations that are already reluctant to reduce CO_2 emissions will latch onto SAI as proof that such reductions are unnecessary.

It's a situation that could negate any benefits that SAI might offer, and one that the Harvard scientists are doing their utmost to avoid. "We really do need to reduce emissions to zero if we want to address climate change," their program director Lizzie Burns said in 2019. "One of the biggest taboos around this technology has been the fear that interests vested in fossil fuels and other processes would benefit from the world slowing down the transition to a zero-carbon energy system."

However, the reality is that even if the SCoPEx mission is successful and SAI eventually proceeds to full implementation, it will only ever be a supplement to CO_2 reduction, not a replacement for it. On another occasion, Burns offered a vivid analogy: "It's like a painkiller. If you need surgery and you take pain medication, it doesn't mean you no longer need surgery."

Andrew May
Space science writer
Andrew holds a PhD in computational astrophysics and has written several books on space and related subjects.

PLANET EARTH: WHY IS IT HEATING UP?

Human activity is causing a rise in global temperatures via the greenhouse effect

© Tobias Roetsch

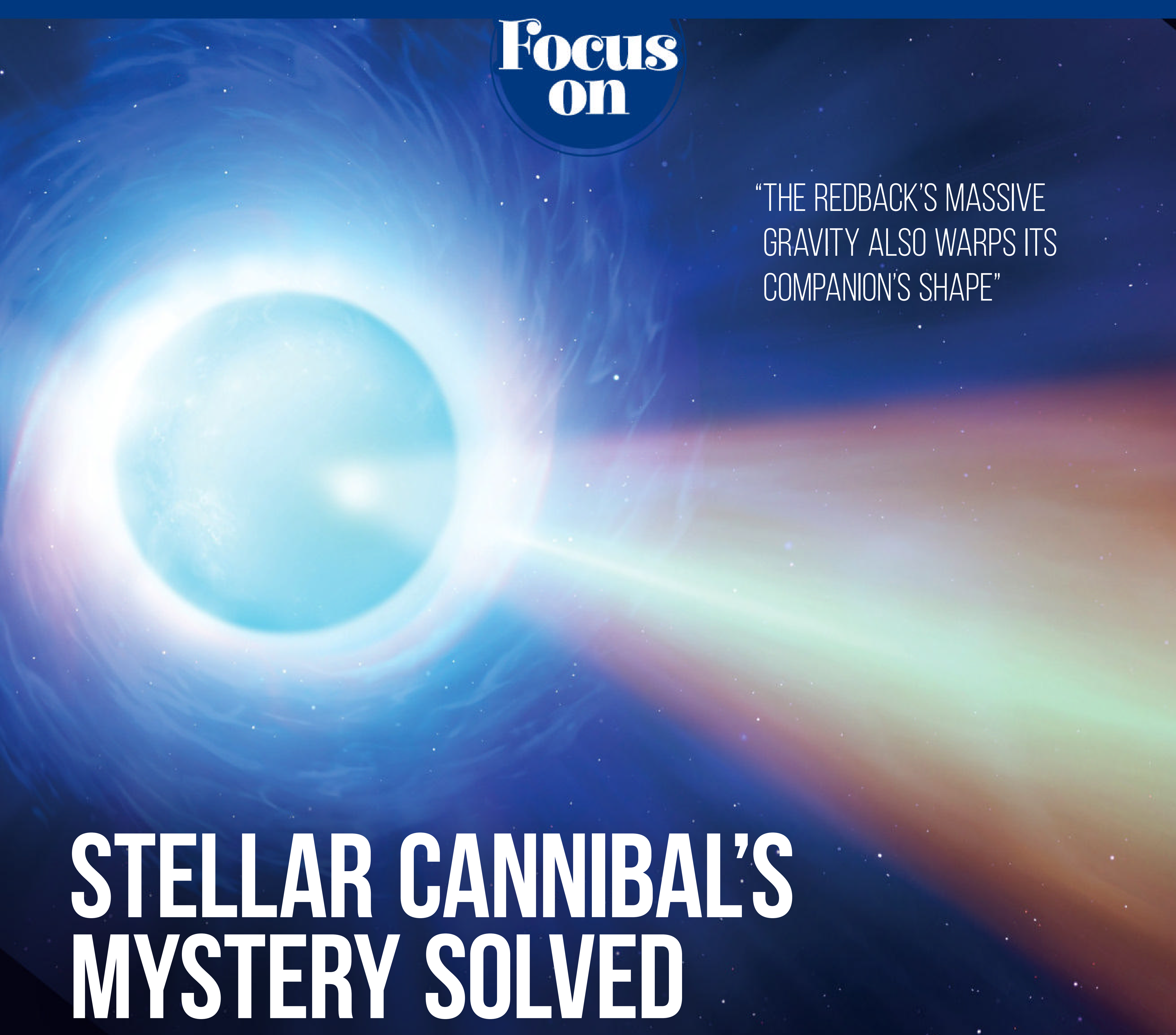
1 GREENHOUSE EFFECT
Beneficial up to a point, heat-trapping gases become a problem if they keep increasing.

2 CARBON DIOXIDE
One greenhouse gas in particular is increasing due to human industrial activity.

3 FOSSIL FUELS IN VEHICLES
Cars, aircraft and other forms of transport produce CO_2 by burning petroleum-based fuels.

4 INDUSTRIAL PROCESSES
Heating, electricity production and similar activities generate CO_2 through the burning of fossil fuels.

5 TREES AND GREENERY
Extensive deforestation produces large quantities of CO_2 through combustion and decomposition of biomass.



Getty

> "THE REDBACK'S MASSIVE GRAVITY ALSO WARPS ITS COMPANION'S SHAPE"

STELLAR CANNIBAL'S MYSTERY SOLVED

A fast-spinning neutron star is ripping its companion apart as they orbit one another

The mystery at the heart of an unexplained bright point of gamma-ray light in the sky has been solved: there's a deadly spider star flaying a second wimpier star to bits, sending out rapid-fire bursts of gamma radiation in the process.

'Black widows' and 'redbacks' in astronomy are species of neutron stars - the ultradense remnant cores of giant stars that exploded. Some neutron stars, called pulsars, rotate at regular intervals, flashing like lighthouses. The fastest spinning among them are millisecond pulsars. When a millisecond pulsar is locked in a rare tight orbit with a lightweight star, it slowly shreds its partner to bits with each rotation. These binary cannibals are known as black widow or redback stars, named after spider species. Now, with the help of citizen scientists, a team of researchers has revealed a new redback at the heart of a bright system known as PSR J2039-5617.

Since its discovery in 2014, researchers have suspected that PSR J2039-5617 contained a millisecond pulsar and a second star. The bright source of X-rays, gamma rays and visible light closely matched the expected traits of such a system. But proving it required lots of telescope data and more number crunching than a typical desktop computer could do in a century.

To prove that the star system was indeed a redback, the researchers leaned on the computing power of Einstein@Home, a project of the LIGO Scientific Collaboration and Germany's Max Planck Institute where more than 500,000 volunteers let their idle computers work together on complex astronomy problems.

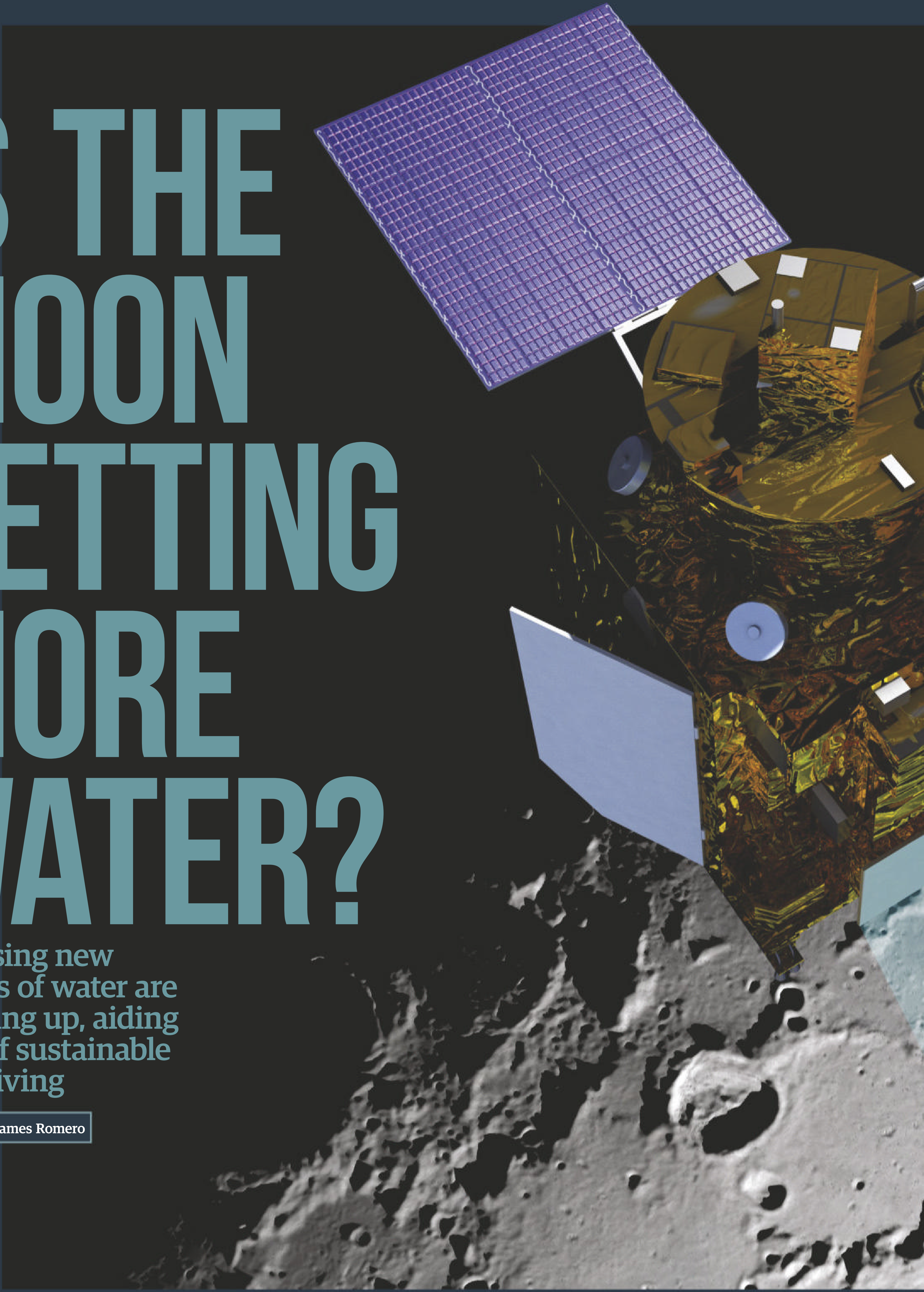
In two months the researchers revealed that PSR J2039-5617 indeed houses a deadly redback, heating up one side of its companion star so that side appears brighter and bluer. The redback's massive gravity also warps its companion's shape, causing "the apparent size of the star to vary over the orbit," said Dr Colin Clark, a University of Manchester astronomer.

The redback star's radio emissions also sometimes get eclipsed by material blown off the surface of the companion star. All those features of the complex system produce strange, varying light patterns.

IS THE MOON GETTING MORE WATER?

Surprising new sources of water are springing up, aiding hope of sustainable lunar living

Reported by James Romero



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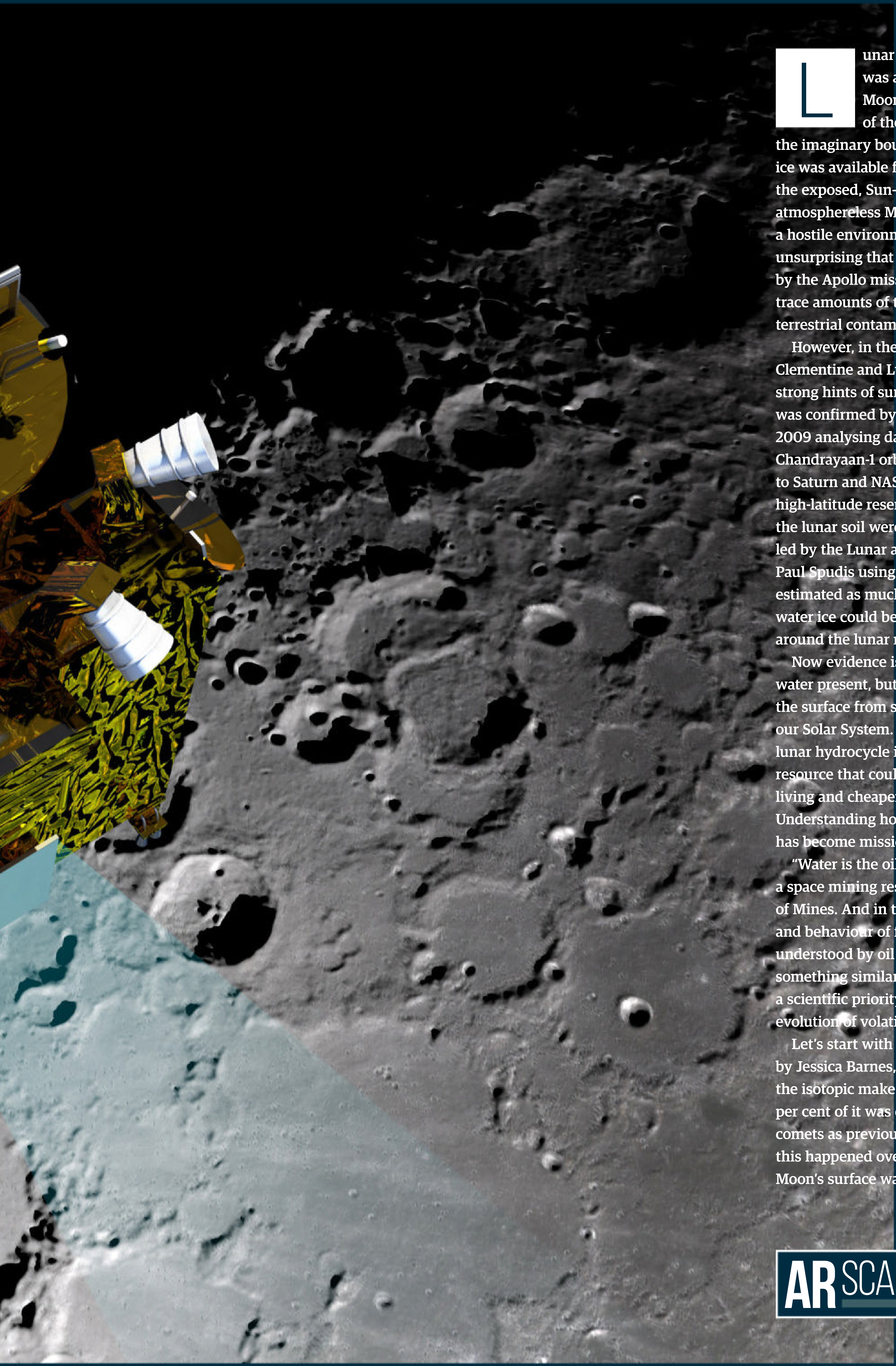

Lunar water was a myth before it was a mystery. Like Earth, the Moon formed on the wrong side of the Solar System's snow line, the imaginary boundary beyond which water ice was available for planetary assembly. Later, the exposed, Sun-scorched surface of our atmosphereless Moon continued to provide a hostile environment for water. It's perhaps unsurprising that when samples brought back by the Apollo missions were shown to contain trace amounts of the stuff, the verdict was terrestrial contamination.

However, in the 1990s, two NASA orbiters, Clementine and Lunar Prospector, provided strong hints of surface water at the poles. This was confirmed by a series of landmark papers in 2009 analysing data from three missions: India's Chandrayaan-1 orbiter, Cassini's flyby on its way to Saturn and NASA's EPOXI spacecraft. The high-latitude reservoirs of 'dirty ice' buried in the lunar soil were vast in scale. A 2010 analysis led by the Lunar and Planetary Institute's Paul Spudis using Chandrayaan-1's radar data estimated as much as 600 million tonnes of water ice could be locked up in just 40 locales around the lunar north pole.

Now evidence is building that not only is lunar water present, but it is being actively supplied to the surface from some surprising sources around our Solar System. Understanding this more exotic lunar hydrocycle is key. Water is an invaluable resource that could open up possibilities of lunar living and cheaper access to Mars and beyond. Understanding how water behaves on the Moon has become mission critical.

"Water is the oil of space," says George Sowers, a space mining researcher at the Colorado School of Mines. And in the same way the properties and behaviour of fossil fuels are keenly understood by oil prospectors, Sowers believes something similar is needed for lunar water. "It's a scientific priority to understand the origin and evolution of volatiles like water on the Moon."

Let's start with that origin. A 2016 study led by Jessica Barnes, then at the Open University, of the isotopic make-up of lunar water indicated 80 per cent of it was delivered by asteroids, not icy comets as previously suspected. Barnes believes this happened over 4 billion years ago when the Moon's surface was a magma ocean, and that the

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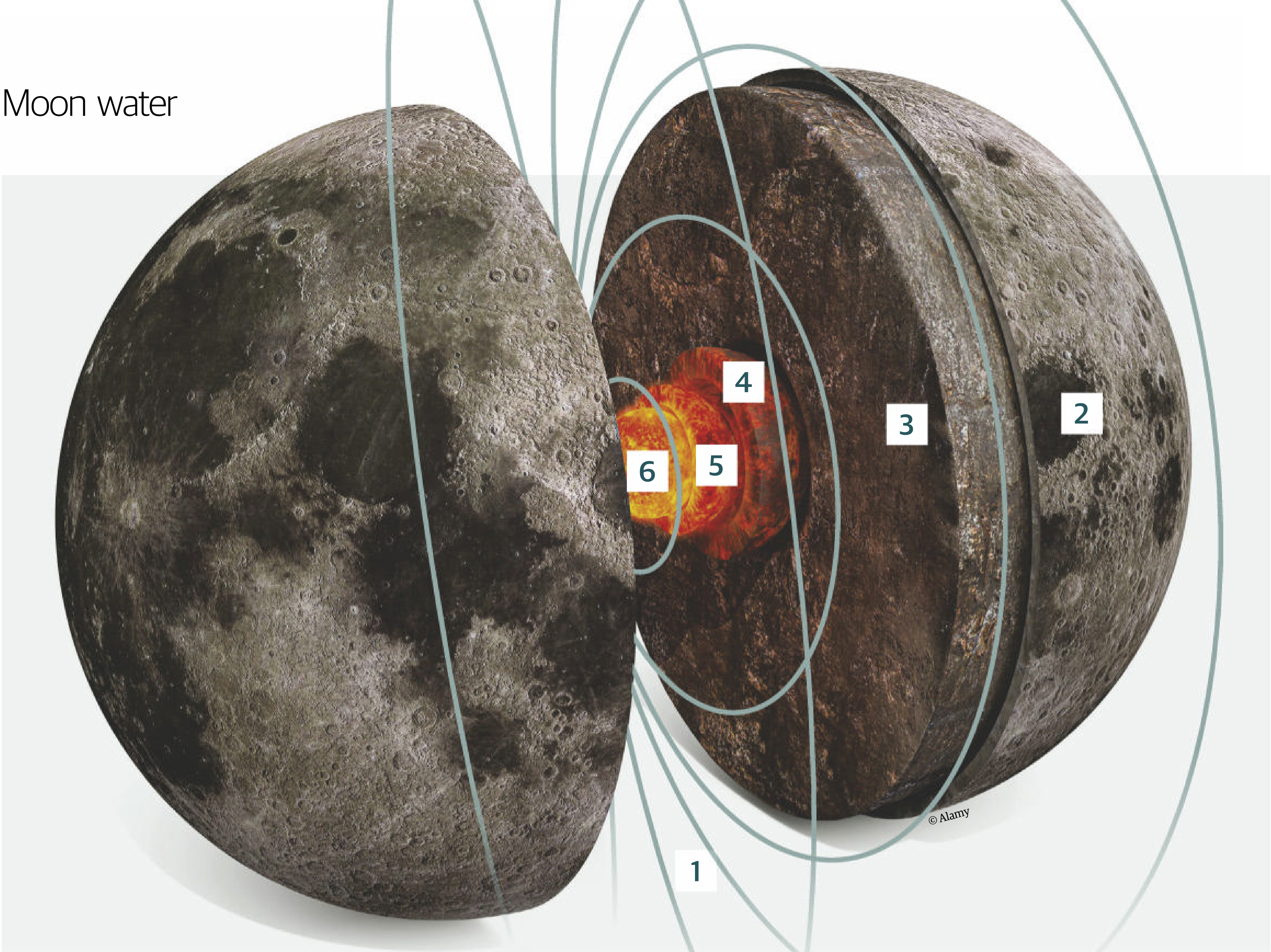

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ALL ABOUT THE MOON

Recent seismic and gravity measurements from lunar orbiters have revealed the different layers of the Moon

1 An ancient magnetic field

Analyses of lunar samples showed the lunar crust contains evidence of a mysterious ancient magnetic field, though what produced it remains unknown.

2 A low-density skin

The lunar crust is made up of lighter minerals like feldspars that crystallised out of the Moon's ancient surface-wide magma ocean as it cooled.

3 The main mantle

The majority of the Moon is mantle, made up of denser minerals like olivine and pyroxene. It is within this vast layer that we think 'moonquakes' originate.

4 Lower mantle

Between the core and mantle is the partially melted lower mantle. The gradual change in composition towards denser minerals continues, as weighty olivine dominates here.

5 A flowy outer core

High temperatures and low pressures mean this iron-rich layer is partially liquid. This may have provided sufficient flow for an early magnetic field-inducing dynamo.

6 A small inner core

At temperatures of around 1,600 Kelvin, at the centre of our Moon you find a 482 kilometre (300 mile) wide sphere composed entirely of solid Iron.

giant outer planets' migrations into their present orbits was disrupting the asteroid belt.

Once the crust had cooled, volcanic eruptions would periodically bring this water to the surface, as evidenced by water-borne minerals and glasses identified within lunar pyroclastic deposits by the University of Hawaii's Shuai Li. While comets and micrometeoroids could also add to any surface reservoir, these energetic impacts on solid crust would likely evaporate much of the water away, and could even represent a net loss of surface moisture.

Even if water molecules do make it safely onto the lunar surface, they will struggle to survive anywhere near the equator, where temperatures can reach a blistering 120 degrees Celsius (248 degrees Fahrenheit) due to the lack of atmosphere. Salvation is to be found at both the poles. Here the Moon's lack of an orbital tilt means the Sun never rises too high in the sky - and never rises at all within its permanently shadowed craters.

At around -230 degrees Celsius (-382 degrees Fahrenheit), these depressional cold traps rival parts of Pluto as some of the coldest places in the Solar System. This has allowed them to steadily accumulate infalling water molecules throughout the history of the Moon, growing them enough to be spotted 100 kilometres (62 miles) up by orbiters like Clementine and Lunar Prospector.

As more satellites were sent to explore the lunar high latitudes, back on Earth a multitude of agencies, space architects and engineers had a new focus for their creative visions of humanity's long-awaited return to the Moon. Lunar settlement would focus on polar exploration, setting up bases in the shadowy cratered terrain of our celestial companion. The rationale was clear: save mission weight and costs by tapping an abundant in-situ resource. A resource that could not only quench astronauts' thirst, but also, through electrolysis reactions splitting hydrogen-oxygen bonds, provide breathable oxygen and hydrogen rocket fuel for return or onward missions.

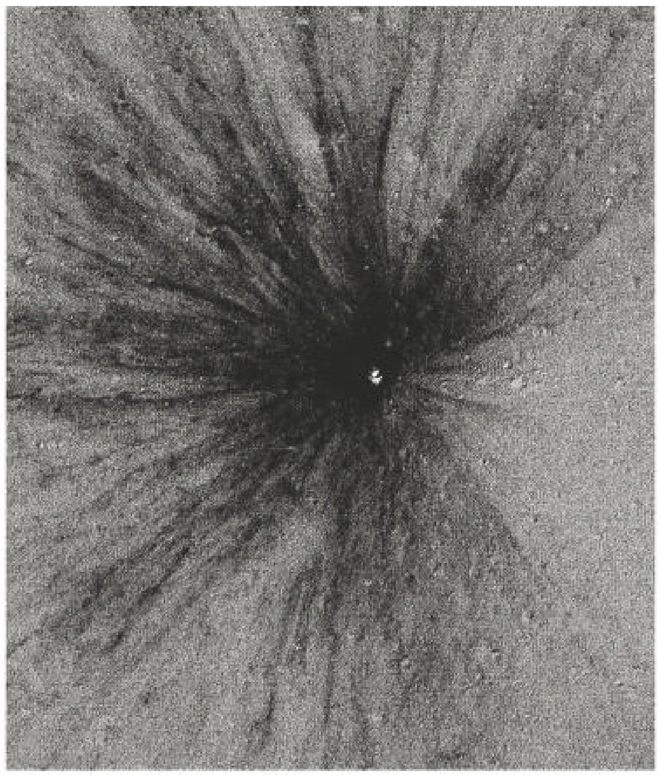
But are missions aiming too high? Last year the Stratospheric Observatory for Infrared Astronomy (SOFIA) discovered vast quantities of watery chemistry bound within regolith particles in the sunbaked lower latitudes. The new data suggested that this type of molecular water could be everywhere across the surface at concentrations as high as 400 parts per million. Perhaps SOFIA's discovery should broaden our lunar horizons? It certainly challenges our understanding of water's origin and continued presence on the Moon.

One way to explain the widespread survival of ancient water across the more exposed parts of the lunar surface is to claim it is not ancient at all - rather its newly arrived. An even better way is to make the Sun the source of this new Moon water. That's exactly what Larissa Starukhina at the Kharkiv National University in Ukraine did back in 2000. She suggested that the protons, or charged hydrogen atoms, raining down on the lunar surface within the solar wind could be freeing up oxygen ions within mineral oxides found in the Moon's top hundred nanometres. The newly freed-up oxygen could then form OH^-, or hydroxyl ions, one of the most common ions in water. As the Sun rises and the surface heats up, any watery chemistry will unbind from its mineral grains, though how much then freely moves across the surface and how much diffuses down further into the regolith is unknown.

Despite this uncertainty, the idea of the solar wind as a hydrating force for those parched equatorial lunar planes has gained traction. Further analysis of data from another Chandrayaan-1 instrument, the Moon Mineralogy Mapper (M^3), showed surface water and hydroxyl distributions across a lunar day's rise and fall with solar flux, as predicted by Starukhina's model.

"We need to find out if the Sun is a source of replenishable water on the Moon, and if there is a significant source there that could be usable for human exploration," says NASA's Orenthal James Tucker. His own recent models on the transport of Moon water across the surface support Starukhina's predictions of how a hydroxyl signature might change with latitude and across the lunar day.

Of course, one way to conclusively prove the solar wind is refreshing the lunar surface would be to turn it off and watch the signs of equatorial Moon water dry up. As it happens, for a few days each month the Moon does indeed take a break from the Sun and its solar wind, during the period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Left: Impacts might add to the Moon's surface water reservoir, though only in small amounts

Below: Permanently shadowed high-latitude craters create cold traps for ancient water that never evaporates

Below left: Solar wind protons could free up hydroxyl ions within lunar regolith to help form water

©NASA

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THE MOON BY NUMBERS

600 MILLION

tonnes of water ice could be stored around the lunar north pole

80%

Estimated proportion of lunar water delivered by icy asteroids during the early Solar System

120°C

Surface temperature found at the dayside equator due to the lack of a lunar atmosphere

-230°C

Temperature of the Moon's permanently shadowed polar craters, which act as water-collecting cold traps

400 PARTS PER MILLION

The proposed concentration of molecular water bound within regolith particles across the lunar surface

100

The number of lunar atmosphere molecules per cubic centimetre. Earth's is 100 billion billion at sea level

© NASA

Left: Traces of water in the Apollo lunar samples were dismissed as terrestrial contamination

AR SCAN HERE

LOOKING AT MOON DUST

it ducks behind Earth. Here it feels the shielding effects of Earth's magnetosphere, the region of space where particles are primarily influenced by Earth's magnetic field.

Recently two studies have looked for surface dehydration during these lunar holidays out of the sunlight. Both of them drew a blank. In 2019, the Planetary Science Institute's Amanda Hendrix, analysing ultraviolet data from the Lunar Reconnaissance Orbiter, found that when the Moon was shielded from the solar wind by Earth, the quantity of water molecules didn't change. This finding was reinforced this year by a Chinese and Japanese team led by Shandong University's Jiang Zhang, who took another look at M^3 data for a second period of lunar sheltering at the start of 2009, finding the same null result.

A nail in the coffin for the solar wind hypothesis? Not exactly. In their paper, Zhang and his colleagues explained their data through another of Starukhina's ideas. The suggestion is that while Earth's magnetosphere is an effective shield from the proton-rich solar wind, it also contains its own wind: the Earth wind. A mixture of deflected solar wind and escaped material from Earth's charged upper atmosphere, it delivers a less concentrated but wider variety of charged particles. This includes protons, but also ions of helium, oxygen and nitrogen, travelling at a variety of energies. Starukhina suggests Earth's magnetosphere can also provide hydrogen atoms for the lunar regolith in the absence of the solar wind.

"For the polar craters permanently shaded from solar wind, the Earth's magnetosphere is the main source of hydration," she claims. To back this up, in 2014 modelling led by Kyoto University's Yuki Harada suggested Earth's magnetosphere could indeed deliver about the same amount of hydrogen ions as the solar wind, especially towards the lunar poles. The theory was given a further boost

HOW THE MOON IS GETTING MORE WATER

Recently two new sources of water have emerged that are making the lunar surface wetter

1 A solar source

The solar wind – which permeates the Solar System – originates in the Sun's upper atmosphere and is made up of a stream of charged particles, primarily protons and electrons.

2 Magnetic deflection

Upon arrival at Earth, the solar wind is largely deflected by our magnetic field. If not for this protection, the solar wind would strip Earth's atmosphere away, just like it did on Mars.

3 Raining hydrogen ions on the Moon

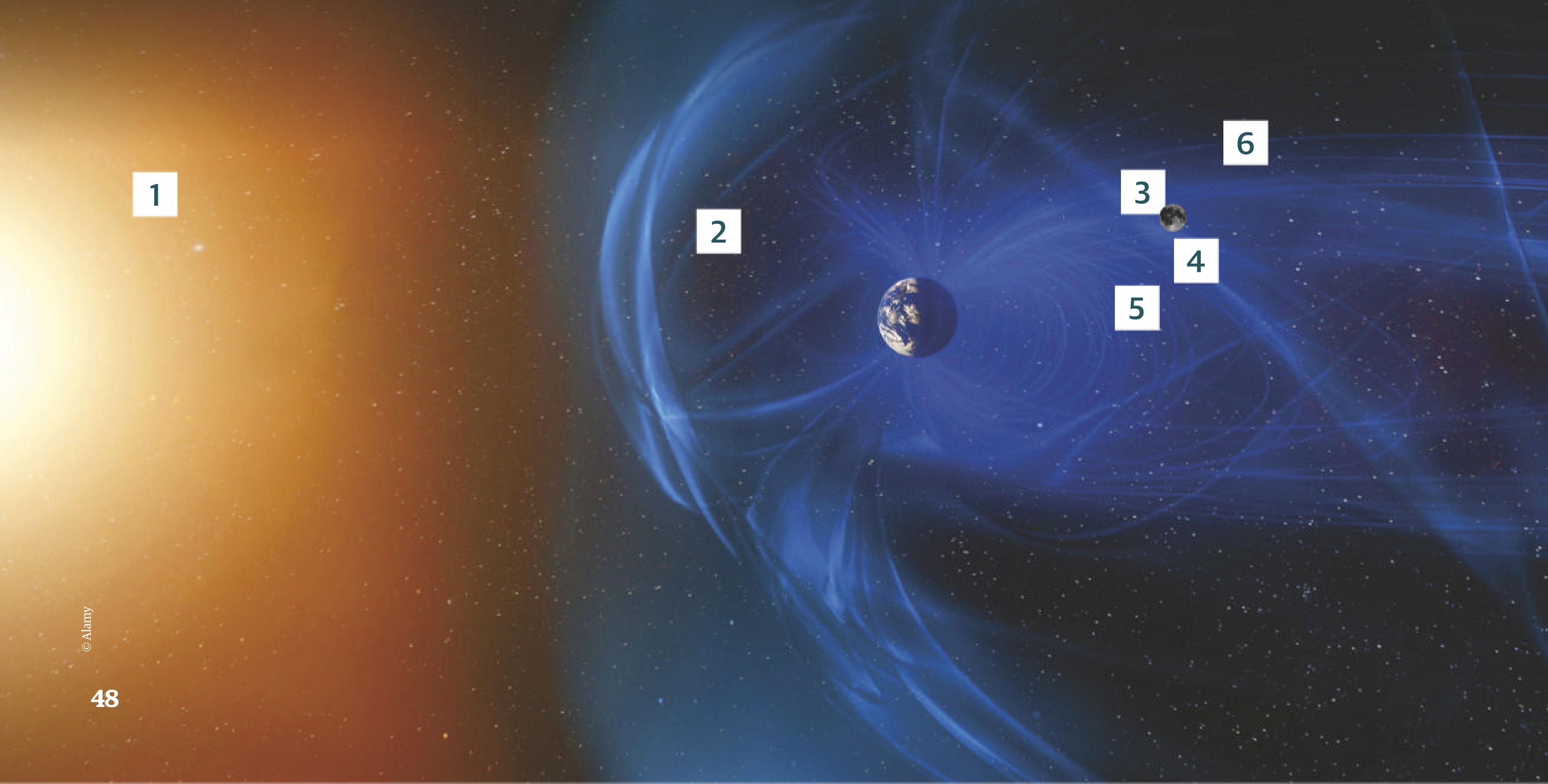
On the exposed lunar surface, solar wind protons could be freeing up oxygen ions within surface mineral oxides to bond with other incoming hydrogen ions to form water.

4 A leaky umbrella

Evidence from the short periods when the Moon shelters from the solar wind inside Earth's magnetosphere suggest it might also be hydrating the lunar surface.

5 A river of ions across space

Our planet's contributions to lunar water come in the form of the Earth wind, a mixture of deflected solar wind and escaped material from Earth's charged upper atmosphere.



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in 2017 when Osaka University's Kentaro Terada, analysing data from Japan's SELENE orbiter, found heavy Earth-wind ions such as oxygen in the vicinity of the Moon. Terada believes these oxygen ions could implant into the lunar regolith to form water, while some of the other fast-moving heavy ions could create large vacancies for future proton emplacement. As a result, he was excited to see Zhang's team invoking Starukhina and the role of the Earth wind in producing the lunar surface water they observed. "I think this is one possibility, but to understand the origin of water more quantitatively, we need ion irradiation experiments and numerical simulations," says Terada.

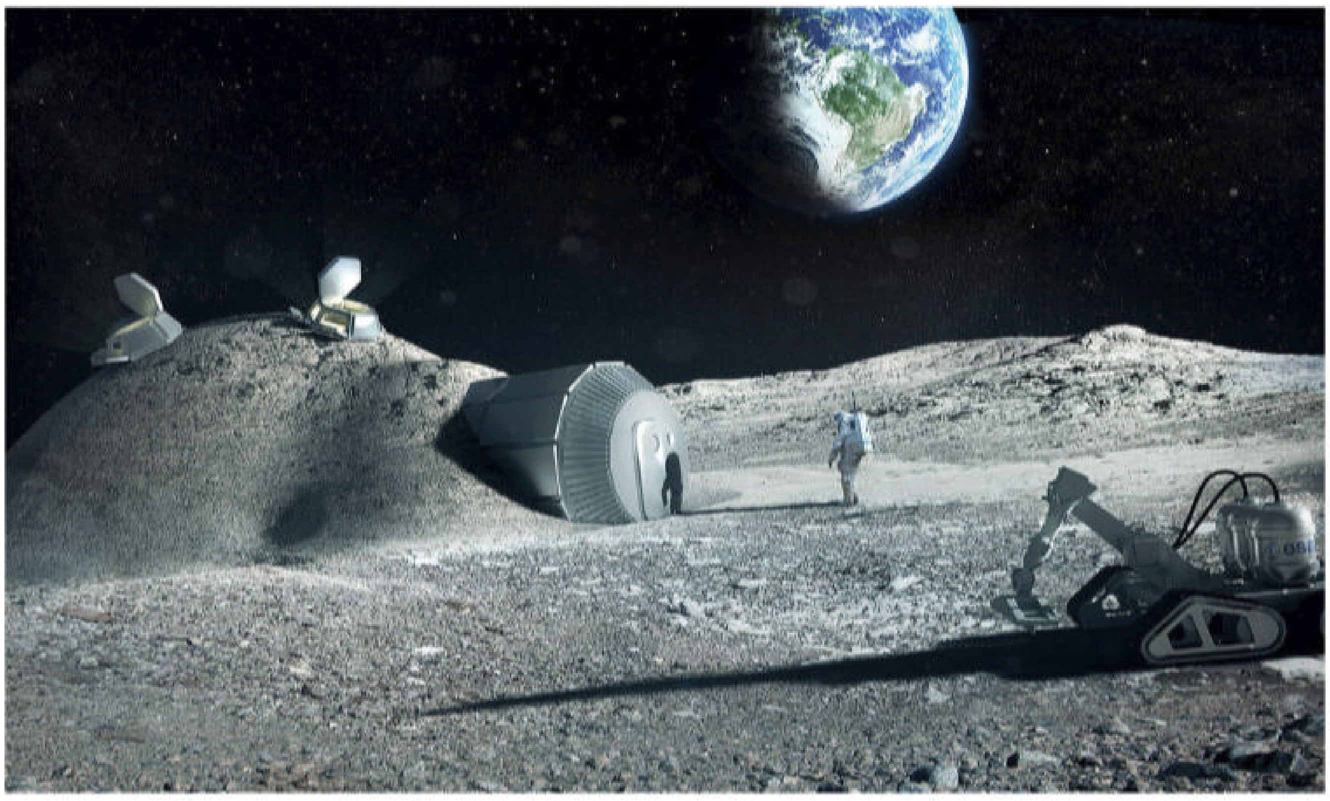
Tucker's preference in terms of future studies are better estimates of the total surface water, which could then be compared with closer approximations of the daytime solar wind source to find the discrepancies that could point to the contribution of the Earth wind. Hendrix, on the other hand, would like to take a closer look at the water load bouncing across the surface through the lunar exosphere: "The detectable levels are pretty low, so that suggests that the current daytime additions to the polar regions of water are relatively low. Whether it's enough to sustain any human activity at the Moon, it's a little too early to say."

If Starukhina's original ideas are confirmed, it means on some level the lunar and terrestrial hydrocycles overlap, linked by an invisible wind of charged particles that flows 380,000 kilometres (236,121 miles) across empty space between planet and moon - a wind that rains down charged particles once evaporated off our oceans or released by respiring plants, which now seeds the parched lunar soil with traces of molecular water. It also means the Moon's water reserve might be increasing. "I think that it probably is getting wetter over time because it has these constant sources," says Hendrix. "But it's at a relatively low level."

As we learn more about a lunar cycle we once thought had dried up billions of years ago, it becomes clearer what a major role water still plays in the surface dynamics of our celestial neighbour, and how little about these processes - critical to any hopes of sustainable lunar living - we know. "We really need to understand that water cycle," says Tucker. "That's critical to understanding what's potentially available to support our operations long term and what type of technologies need to be developed in order to gather that water." From myth to mystery, lunar water is now a primary motivation, fast tracking our return to the Moon.

James Romero
Science writer
James is a former geologist and current science writer covering topics such as astronomy, planetary science, astrobiology and cosmology.

Below: The discovery of water at the Moon's high latitudes has inspired many designs for polar bases



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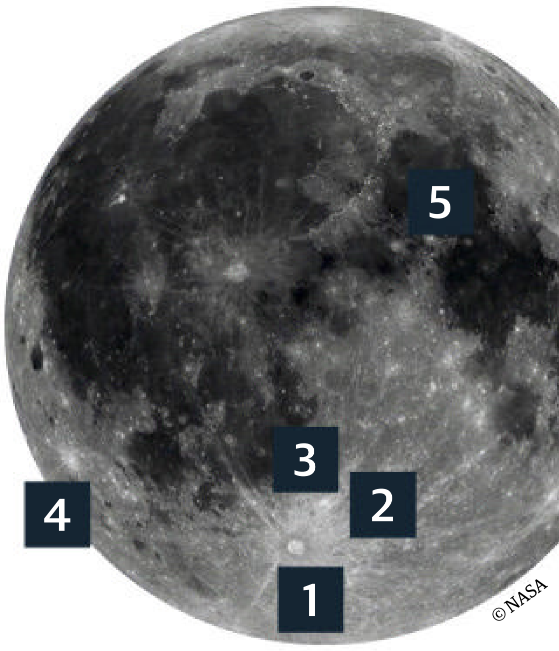

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WHERE IS THERE WATER ON THE MOON?

1 Watery chemistry in Clavius crater

Last year's detection of water molecules in Clavius crater, one of the largest craters visible from Earth, hinted at some degree of surface-wide hydration of the lunar regolith.

2 Tonnes and tonnes of dirty polar ice

The Lunar and Planetary Institute's Paul Spudis used Chandrayaan-1's radar data to estimate that 600 million tonnes of water ice could be locked up in just 40 polar locales.

3 Not exactly poles apart

The pole-to-pole orbit of Chandrayaan-1 allowed NASA's onboard Moon Mineralogy Mapper instrument to map the surface ice across the Moon's southern pole.

4 A wispy, watery atmosphere

It is believed that water molecules freed from lunar regolith grains by the warming Sun might bounce across the surface, travelling through the Moon's thin exosphere.

5 Volcanic water near historic landing sites

In 2017, Hawaii University's Shuai Li found evidence of water in large pyroclastic deposits, including those found near the Apollo 15 and 17 landing sites.

6 A heavy water source

Terada suggested Earth wind oxygen ions could implant into the lunar regolith to form water, while other heavy ions could create vacancies for future proton emplacement.

‘FARFAROUT’ OFFICIALLY THE SOLAR SYSTEM’S MOST DISTANT OBJECT

This recently discovered trans-Neptunian object lies some 140 astronomical units from the Sun

The planetoid dubbed ‘Farfarout’ was first detected in 2018 at an estimated distance of 140 astronomical units (AU) from the Sun - farther away than any object had ever been observed. One AU is the average Earth-Sun distance - about 93 million miles, or 150 million kilometres. For perspective, Pluto orbits at an average distance of about 39 AU.

Farfarout’s inherent brightness suggests a world roughly 400 kilometres (250 miles) wide, barely enough to qualify for dwarf planet status. But the size estimate assumes the world is largely made of ice, and that assumption could change with more observations.

Speaking of more observations, the detection team has now collected enough additional data to confirm the existence of Farfarout and nail down its orbit. As a result, the planetoid just received an official designation from the Minor Planet Center in Cambridge, Massachusetts, which identifies, designates and computes orbits for small objects in the Solar System.

That new designation, announced on 10 February in a Minor Planet Center electronic circular, is 2018 AG37. Farfarout will also receive a catchier official moniker down the road. “A single orbit of Farfarout around the Sun takes a millennium,” discovery team member David Tholen, an astronomer at the University of Hawaii, said. “Because of this long orbital period, it moves very slowly across the sky, requiring several years of observations to precisely determine its trajectory.”

Astronomers spotted Farfarout using the Subaru Telescope on Mauna Kea in Hawaii and traced its orbit using the Gemini North and Magellan telescopes. “Only with the advancements in the last few years of large digital cameras on very large telescopes has it been possible to efficiently discover very distant objects like Farfarout,” co-discoverer Scott Sheppard, a Solar System small bodies scientist at the Carnegie Institution for Science, said.

Farfarout is currently about 132 AU from the Sun, the researchers determined. And its orbit is now known to be very elliptical, swinging between extremes of 27 and 175 AU, thanks to gravitational sculpting by Neptune. “Farfarout was likely thrown into the outer Solar System by getting too close to Neptune in the distant past. Farfarout will likely interact with Neptune again in the future, since their orbits still intersect,” Chad Trujillo, an exoplanet astronomer at Northern Arizona University from the National Science Foundation’s NOIRLab, said.

Because Neptune plays such a large role in Farfarout’s life, the planetoid likely cannot help astronomers in the hunt for Planet Nine, the big hypothetical world that some astronomers think lurks unseen in the far outer Solar System. Planet Nine’s existence has been inferred from its putative gravitational influence on small bodies very far from the Sun, whose orbits cluster in odd and interesting ways. But the small worlds that astronomers look to as breadcrumbs in the Planet Nine search are free of Neptune’s influence, unlike Farfarout.

> “FARFAROUT WAS LIKELY THROWN INTO THE OUTER SOLAR SYSTEM BY GETTING TOO CLOSE TO NEPTUNE IN THE DISTANT PAST”
>
> CHAD TRUJILLO

The team that spotted Farfarout is well known for peering deep into the dark and frigid outer Solar System. In 2018 the researchers also found distant object Farout and a faraway dwarf planet nicknamed ‘the Goblin’. Farfarout’s distance record refers to its current location. There are a number of other objects, such as the dwarf planet Sedna, whose orbits take them much farther away from the Sun than Farfarout’s maximum orbit. And scientists think there are trillions of comets in our Solar System’s Oort Cloud, which begins about 5,000 AU from the Sun.

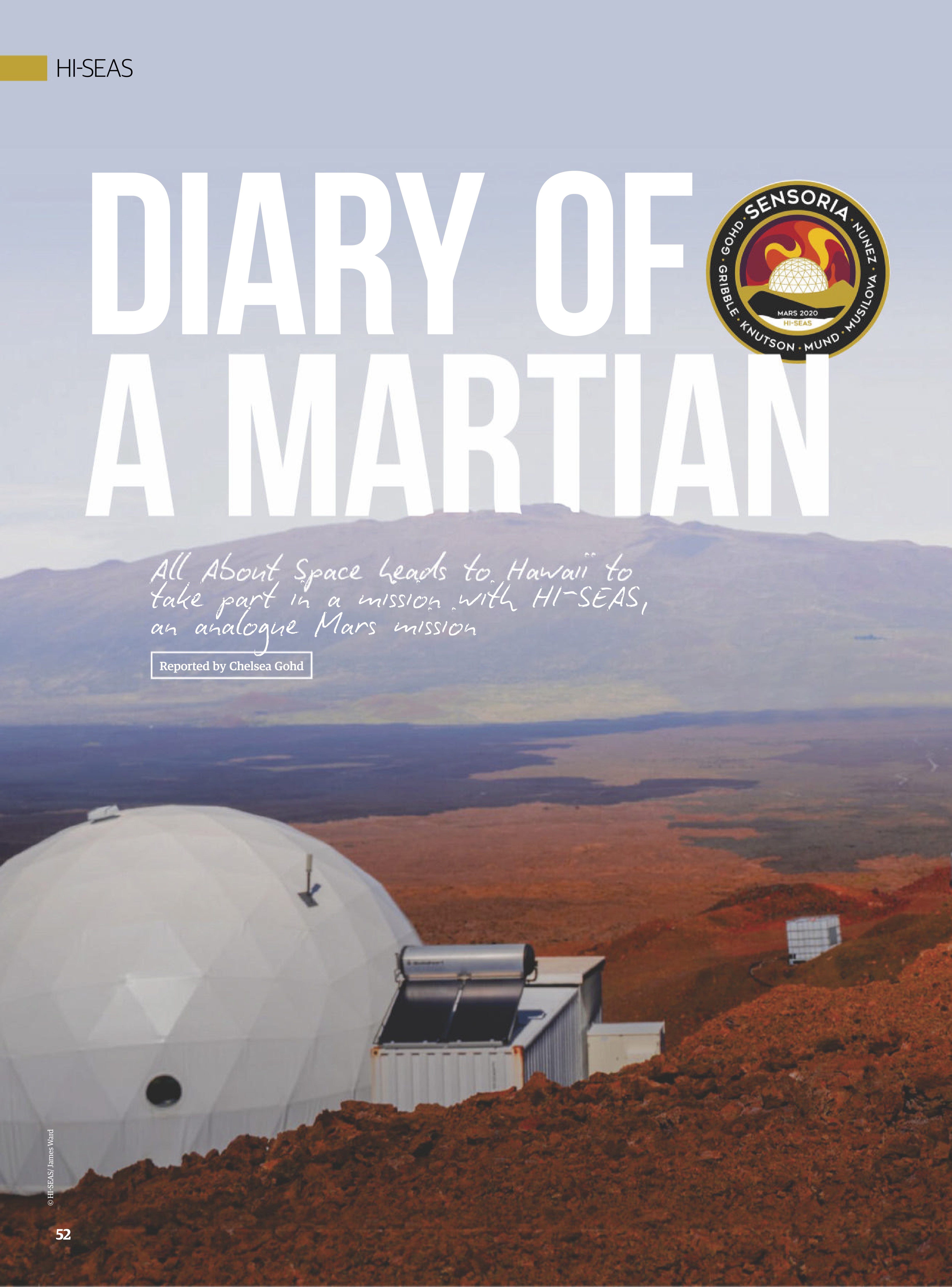
Right: The small, far-flung world is thought to be comprised of ice and rock, like a comet

© NOIRLab

DIARY OF A MARTIAN

All About Space heads to Hawaii to take part in a mission with HI-SEAS, an analogue Mars mission

Reported by Chelsea Gohd



© HI-SEAS/ James Ward

I awoke hours before dawn, stretched myself into a lucid state and put on my shoes. I was ready to go to Mars.

On 2 November 2020 I boarded a plane in Newark, New Jersey, headed for Kona, Hawaii, ready for two weeks on 'Mars'. But for me the trip to the Red Planet didn't take that long, as instead of travelling 190 million kilometres (119 million miles) to the real thing, I instead journeyed to the HI-SEAS (Hawaii Space Exploration Analog and Simulation) research facility, located on the slopes of Mauna Loa, a volcano on the Big Island of Hawaii, to take part in Sensoria M2: an analogue Mars mission. Follow me back in time to November 2020, when I left Earth and spent two weeks on the Red Planet.

Sol 1 (2 November 2020)

LANDING ON MARS

After a two-week quarantine, three COVID-19 tests and an arduous journey through two airports with a face mask, face shield and gloves firmly in place – as I departed amid the coronavirus pandemic – I finally arrived in Hawaii, hastily met my five Martian crewmates, tossed my bag in the back of the HI-SEAS van (a big, capable vehicle aptly nicknamed 'the beast') and buckled in, too exhausted to even realise exactly what I was in for.

For two hours I watched the Hawaiian landscape pass me by out the window – a tease, the humour of which was not lost on the crew. We laughed, foreshadowing the memes we would eventually create, which would read along the lines of 'two weeks in Hawaii: expectations versus reality'. The view out the window turned from a lush green landscape to a seemingly endless sea of red volcanic rock as 'the beast' rocked back and forth, climbing up the volcano.

We arrived at HI-SEAS and reality set in: this little dome on the side of a volcano was to be my home for the next two weeks. Turning out from the futuristic white dome, the beauty of the natural terrain took me by surprise. It really looked like Mars, with Olympus Mons (or rather Mauna Kea) standing proudly in the distance. Now, while it was late when we arrived, we had to learn a few things about life in the 'hab'.

Most notably we were given a rundown of the bathroom, which had a shower with a bucket, a composting toilet and a urinal. The urinal is for all-gender use, as urine caused issues with the composting toilet in the past. As I tried to wrap my head around living on Mars for two weeks, me and the rest of my all-woman crew also learned how to use a urinal. I eventually fell asleep with the sounds of explosions in the distance; the sounds of 'Space Force' testing explosives on Mars (a nearby military base).

Sol 1

© Chelsea Gohd

Sol 2 (3 November 2020)

AN ELECTION AND ADJUSTING TO MARTIAN LIVING

My first full day on Mars was interesting, as it coincided with the US presidential election. While I would usually probably be tuned in to the news all day, I was now in a bubble with my only connection to the outside world being email – and each email takes 20 minutes to send and 20 minutes to receive, a total communication delay of 40 minutes.

I woke up extra early because of the 'Martian jet lag', stretched, exercised, once again attempted to use the all-gender Martian urinal and checked my email. Once everyone was up, the crew convened over a breakfast of Martian pancakes, and I launched into a busy day, which was an appreciated distraction from the election happening back home 'on Earth'.

I worked with my crewmates on inventory, accounting for every single item in the dome (tedious, but important). And as chief science officer conducted the first of three 'swab parties'. Essentially, I led the crew through swabbing themselves and the habitat interior. These samples will be used for an experiment studying what microscopic critters were living on us and our home on analogue Mars.

That evening we realised that our power (which comes from a solar panel outside) was low, so we shifted into a low-power mode. Again I fell asleep to the soothing explosive sounds booming from Space Force nearby.

Sol 3 (4 November 2020)

THE LIGHTS ARE OFF ON MARS

I woke up early again, but when I reached to switch on the lamp in my quarters, nothing. Investigating further, I climbed down the stairs, and sure enough, no power. Officers Brandy Nunez, Richelle Gribble and Beth Mund joined me, and officer Mund led the charge in making a food staple that didn't require power or much water: protein balls. Essentially a rolled-up mixture of uncooked oats, coconut oil, peanut and cocoa powder and whatever else we felt like throwing in there.

Officer Amanda Knutson and commander Michaela Musilova checked out the batteries in the engineering bay and found that there was a temporary but solvable battery issue. We had electricity again!

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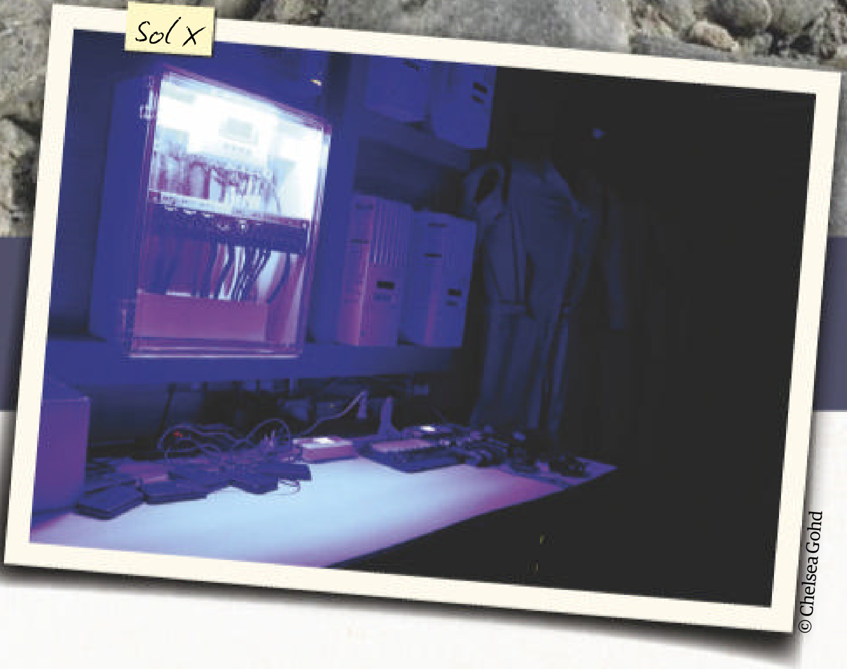

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Above: Views from the dome really do resemble pictures taken by Mars rovers

Right: The hab has a small lab where experiments can be conducted

Sol 4 (5 November 2020)

NO SHOWERS FOR THE CREW

I awoke to a beautiful, sunny day on Mars. After all the travelling and working in the hab, I would have loved to take a shower, but this morning our water tank hit a new low: nine per cent. We were awaiting a drone water resupply mission, but that water wasn't set to arrive until Sol 7, so it was time to get serious about conserving resources. But low water levels aside, I was really looking forward to my first EVA: a quick jaunt to the 'waterfall of death', a nearby crater, and 'Mordor', a lava tube so massive and foreboding it's too dangerous to even send a robotic probe into.

To prepare, commander Musilova led us through some geology basics. We set up our communication devices and linked our navigation devices with the destination coordinates. At least one crew member would always stay at the habitat for EVAs (they serve as HABCOM, helping the crew to get out and back safely). Finally, we suited up.

Putting on a spacesuit for the first time was beyond exciting. I couldn't be more thrilled to be breathing heavy under the helmet, peering out the visor to a landscape that looked distinctly Martian. I didn't care that my back hurt under the heavy life-support pack. I didn't care that my fingers felt dull and disconnected in the thick gloves – I was ecstatic.

Sol 5 (6 November 2020)

A SLEEPY STARTCREW

There are no weekends on Mars, but we chose today to have a later-than-usual start, which I was thankful for, as despite my best stretching attempts I was still sore from the EVA the day before; the lava rocks would've been challenging to scramble over without a heavy suit and helmet.

A slow day, I got some work done and served as HABCOM for the second EVA.

That night, I put on a show. When I'm not talking and writing about space and science, I'm writing and performing music as my alter ego Foxanne. With a small travel guitar, I sang a handful of songs about Mars rovers, life, love and loss. It was a nice way to bond, and I was really starting to feel like we were a crew.

© HI-SEAS/Lain Velasco

Right: The helmets where heavy, but necessary when leaving the habitat

Below: Water was scarce while we waited for a resupply mission to fill up our tank

Left: Setting up a camera to capture footage of our exploration of an alien world

Sol 7 (8 November 2020)

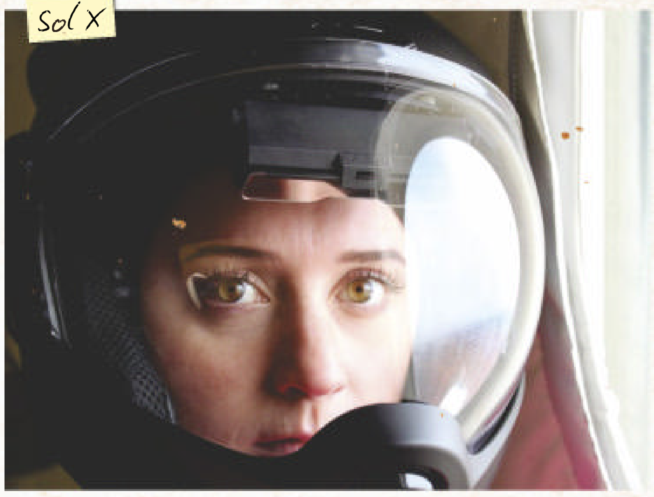
THE MOST INCREDIBLE EVA

This morning we reached a new water low: six per cent, or 29 gallons. Luckily, today a 'drone mission' arrived and refilled our water tank.

And most exciting of all? Officers Nunez and Knutson found a new urinal filter!

While the wind was still strong outside, the storm had passed enough for us to go out on EVA3. Today we went on a longer excursion, out to the lava tube Caradhras (like Mordor, it was named after a mountain from the Tolkien universe).

A three-hour excursion round trip, we trekked across the edge of Mordor out to Caradhras. Descending into the lava tube was much tougher than expected, as the heavy helmet makes it challenging to bend over and it's tough to tell which lava rocks will hold weight and which will slip out from under your feet. Additionally, breathing in a helmet while at such high altitudes while scrambling through lava tubes is not easy. I was sucking wind for sure.



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Sol 8 (9 November 2020)

NEVER A DULL MOMENT

I woke up exhausted and giddy from the EVA the day before, and went to go brush my teeth. A yellow sticky note was stuck to the faucet. "No water," the note read. Sure enough, lifting the handle didn't reveal anything, not a single drip.

Jumping into 'crisis mode', I went downstairs and explored the other faucets. One faucet in the laboratory had a slow drip coming through, so while we figured out what was going on, I opened the faucet and we started filling up buckets and bowls with emergency water.

Officer Knutson and commander Musilova quickly got into their spacesuits to check out the water system outside of the hab. Still with no clear solution, the 'repair drones' returned to try and fix the issue. They discovered an issue with our water pump, and in the interim while they retrieved a replacement, they delivered some emergency drinking water.

To make the day just a bit stranger, I ended the day by conducting the second 'swab party'. After pouring a glass of water from a bucket on the floor, I walked my crewmates through swabbing our forearms and toes… for science.

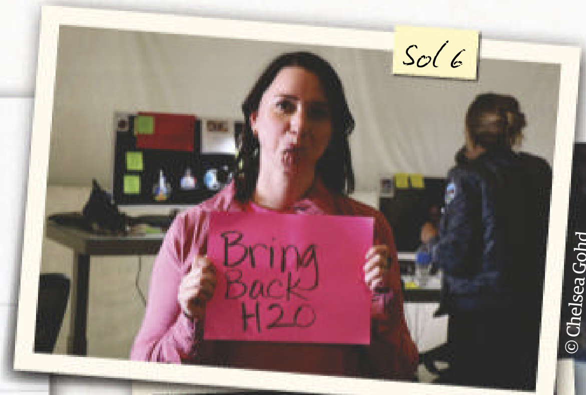
Sol 6 (7 November 2020)

RELIEVED BUT RUNNING OUT OF WATER

I woke to the news that Joe Biden and Kamala Harris won the US presidential election. As we were a diverse group of new colleagues I didn't want to presume others' reactions, but quietly celebrated, breathing a heavy sigh of relief.

Unfortunately, a 'dust storm' rolled in overnight. The EVA gear is susceptible to damage in storms, and slippery lava rocks could lead to severe accidents, so EVA3 had to be postponed.

Unshowered and sleepy, likely because of some combination of the jet lag and my slightly lower-than-normal oxygen levels, I called it a night after a long day of working indoors.



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© HI-SEAS/Michaela Musilova

Right: EVAs were conducted to explore 'Martian' lava tubes and terrain

© Chelsea Gohd

Left (main): Exercise was an important part of daily life inside the Martian habitat, keeping our bodies healthy

Left: A puzzle of home kept us occupied while we were stuck inside the hab

Below: Analysing the rocks of 'Mars' on an EVA

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Sol 9 (10 November 2020)

BAD WEATHER AND NO WATER ON MARS

I woke to the remainder of our water being just one five-gallon bucket. The 'repair drones' were set to return by lunchtime, but now we also had no electricity in the lab or the bathroom downstairs. Luckily when they returned again they were able to repair the pump, and we could finally breathe easy about our water access.

A slow day, as we couldn't safely go on an EVA with our shaky water and power access, I worked indoors throughout the afternoon. We did a 3D puzzle as a crew, and as part of this days' exercise (we exercised for at least 30 minutes every day, as astronauts have to maintain a rigorous exercise regimen), commander Musilova led us through a hula routine.

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Sol 10 (11 November 2020)

ANOTHER SLOW DAY

Another dust storm rolled in, and so yet again we were stranded inside. After ten sols with just a couple of chances to get outside, I was starting to feel a bit antsy. But I decided to get busy to keep from feeling too cooped up.

I worked on my own projects, exercised and even worked on some art, writing a bit of music and painting with blue spira algae and reddish iron-oxide powder - materials that officer Gribble brought as realistic Martian art materials as they are dehydrated and lightweight.

It was at this point during the mission that someone said the word 'pizza' and I really started to miss real Earth food.

But just as I was starting to feel a bit down and worn out, officer Mund received an email. But this was no ordinary email. Inside was a short video sent from NASA astronaut Christina Koch, who cheered us on on our analogue journey. The heartfelt message from someone who is such an inspiration was overwhelming. I'll admit it, there were tears.

Sol 11 (12 November 2020)

ANOTHER STORMY DAY

This was another stormy day. The winds brought a chill into the dome and I bundled up, trying to stay warm as the dust storm raged on. For a few brief moments in the afternoon, the clouds cleared and a few crew members suited up for a brief EVA... just to take out the trash. I served as HABCOM for the trashwalk, and I knew that we'd been stuck inside a long time when I felt jealous that I wasn't suiting up to go take out the trash.

At this point I felt both as if I'd just arrived and had finally adjusted to life in the hab, but I also felt like I'd been there for ages, bonding with my crewmates and making a life 'on Mars'. Hopefully the storm subsides tomorrow.

"The winds brought a chill into the dome and I bundled up, trying to stay warm as the dust storm raged on"

Sol 12 (13 November 2020)

COLD AND TRAGIC

Another chilly morning in the hab brought an even colder realisation: one of officer Knutson's fish died. She brought a live animal research project into the hab, the first ever at HI-SEAS, but while two of the three fish continued to survive, one of the fish met an untimely fate. I helped officer Knutson deal with the fishy situation in the lab, and then got to work in the hab. After relaxing for a moment with my makeshift Martian watercolour painting set-up, I looked out the hab window and - yahoo! - a brief break in the storm.

Me and three crewmates rushed to suit up, racing the weather. I was elated to step outside and even just feel the breeze against the outside of my spacesuit. However, just about 30 minutes into the journey, as I was exploring around Mordor, I saw clouds looming on the horizon. I looked back at my crewmates and we agreed to return to the hab, communicating with hand motions like scuba divers do.

Picking up pace on my way back to the habitat, the storm chasing me, I got back just in time.

Sol 13 (14 November 2020)

A MARTIAN BIRTHDAY

While the storm continued on through Sol 13, the third-to-last day in the habitat, it was a day to celebrate, as it was also officer Mund's birthday. She surprised us with a 'birthday wig', setting a festive atmosphere that immediately lifted the mood in the hab. The storms caused us to go back into low-power mode (never a dull day), but that didn't stop us from throwing an impromptu birthday party after working through the day.

I decided to make a no-bake powdered cheesecake and royal icing that I dyed blue with the spira algae. The result was more like a strange alien pudding, but wow was it delicious. We sang happy birthday, danced it out and with a small power reserve and a hard drive with movies on it, watched *Star Wars: Rogue One*, a perfect ending to the strangest birthday party I've ever attended.

Sol 14 (15 November 2020)

LOW ON POWER, HIGH ON INSPIRATION

The second-to-last day in the habitat, we were still having power issues, and getting this close to the end of the mission, I was feeling cold and fairly exhausted. After getting some work done in the habitat, I joined my crewmates for lunch. However, lunch quickly turned into a group watercolour painting session at the living room/dining room/kitchen table.

It was fun getting creative as a crew, but soon we all paused our painting, stopping in our tracks as a prerecorded version of SpaceX's Crew-1 launch, which had happened earlier that day, arrived by email. We all gathered around a laptop screen to watch the historic flight, and silence burst into raucous cheering when the four astronauts blasted off safely and successfully.

© Chelsea Gohd

Above: With a 40-minute delay on news and email, we couldn't watch anything live

Below: The land surrounding the dome was desolate and deserted, much like the real Mars

© HI-SEAS/Hillary Coe

Sol 15 (16 November 2020)

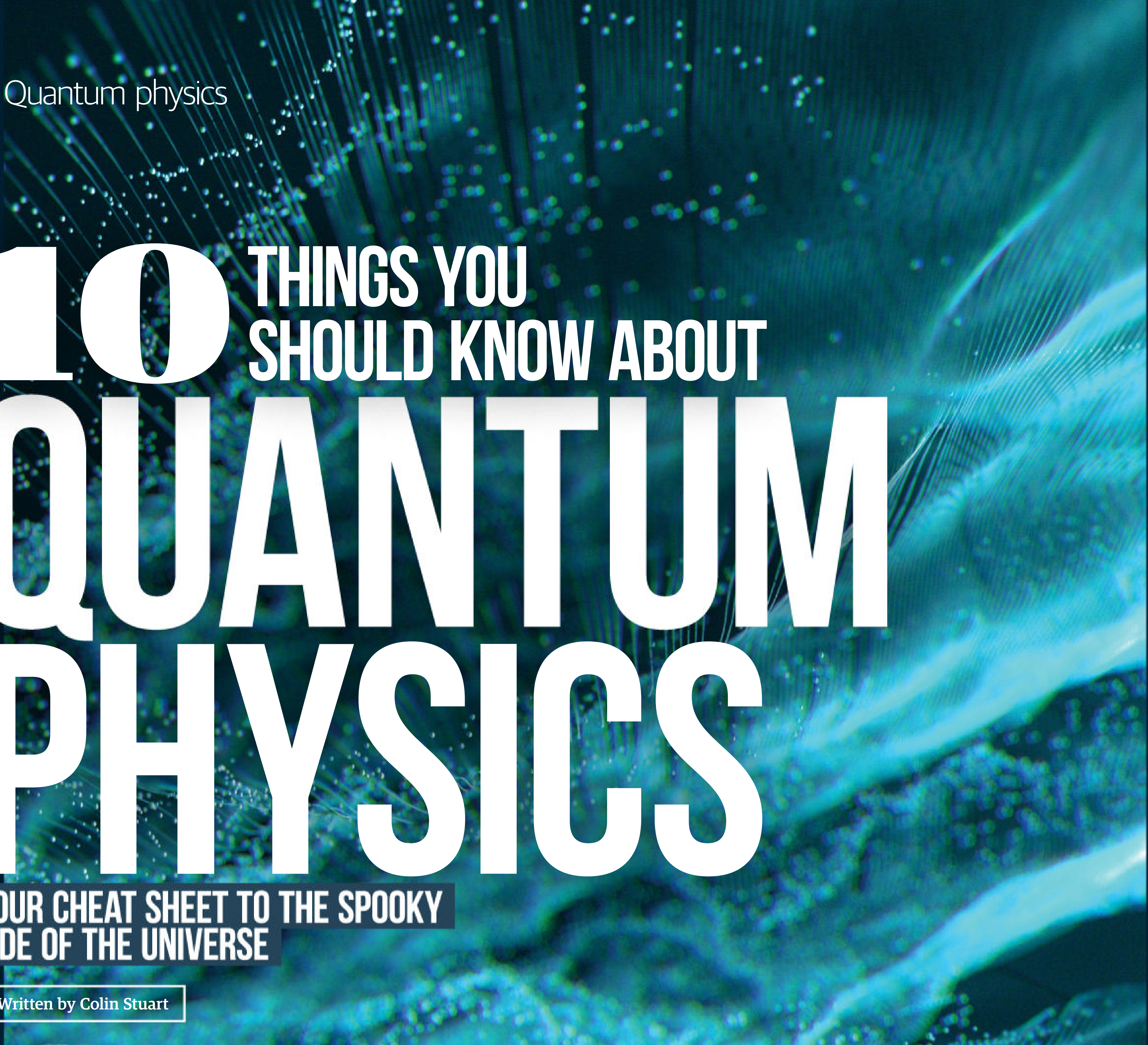
LAST DAY!

Somehow it was the last day. We all spit into tubes for Lifeship, an effort to send human DNA to the Moon. After we sealed our tubes, we ended the simulation, stepping out of the habitat and returning to Earth. It was truly overwhelming. The breeze against my bare skin was something I'd been looking forward to.

With the simulation over and fairly clear skies, commander Musilova led us on one last trek back to Caradhras, as the weather kept us from conducting as many EVAs as crews are usually able to. Without the burden of the suit, pack and helmet, I felt superhuman climbing unencumbered into the lava tube.

After journeying back from our thrilling hike, still intoxicated by the fresh air and cool breeze, we returned to the hab and got to work cleaning and packing, which took the majority of the day. Driving away from HI-SEAS, it finally felt over. And while my friends joked about how they wished they could 'leave Earth' for the election and for two weeks of the pandemic, the single most palpable feeling I had after completing the mission was joy for how incredible our planet is.

As lava rocks out the van window once again turned into lush greenery and pink flowers, and the diverse beauty of planet Earth revealed itself, that feeling only continued to grow.



10 THINGS YOU SHOULD KNOW ABOUT QUANTUM PHYSICS

YOUR CHEAT SHEET TO THE SPOOKY SIDE OF THE UNIVERSE

Written by Colin Stuart

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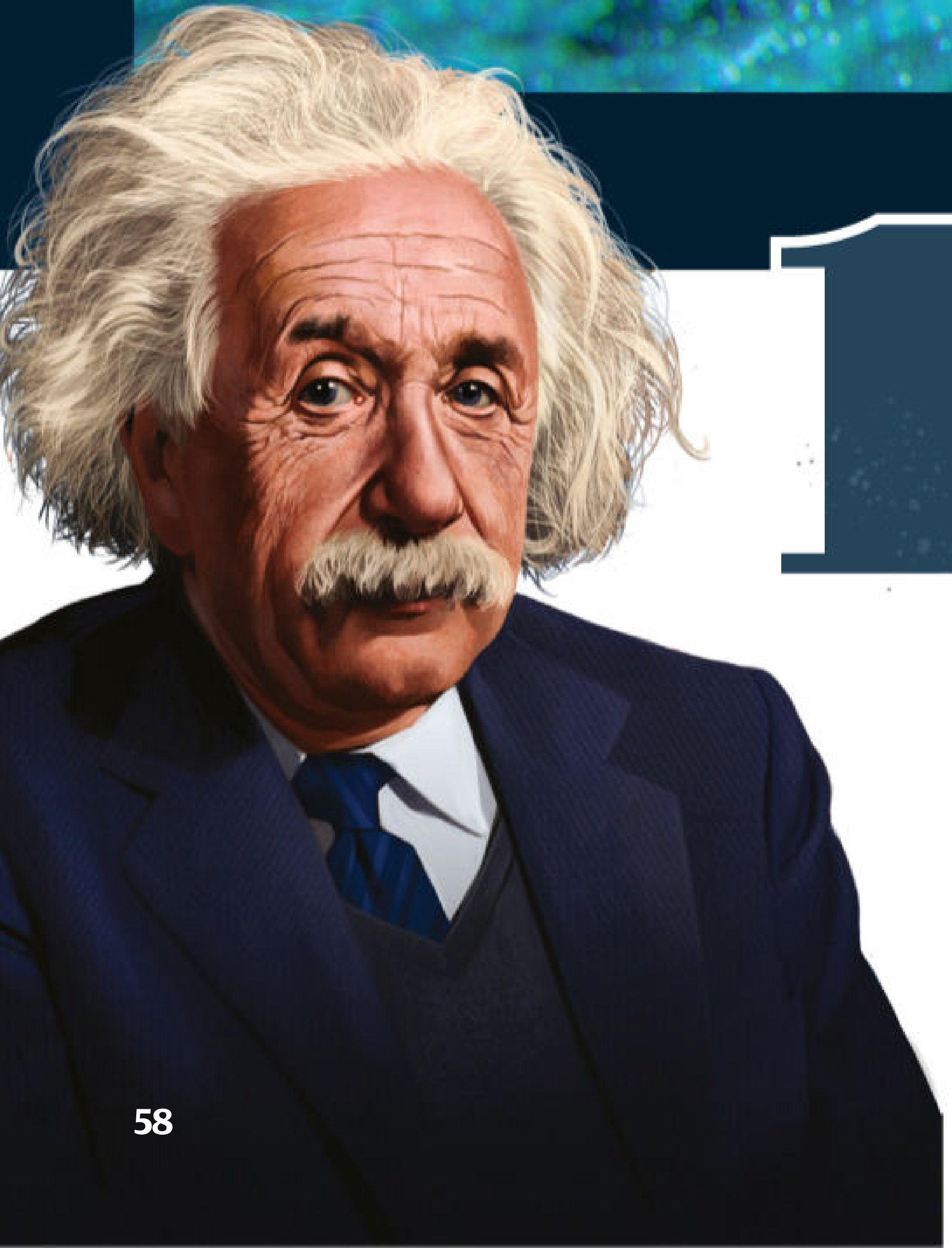


1 THE QUANTUM WORLD IS LUMPY

The quantum world has a lot in common with shoes. You can't just go to a shop and pick out trainers that are an exact match for your feet. Instead you're forced to choose between pairs that come in predetermined sizes.

The subatomic world is similar. Albert Einstein won a Nobel Prize for proving that energy is quantised. Just as you can only buy shoes in multiples of half a size, so energy only comes in multiples of the same 'quanta' - hence the name quantum physics.

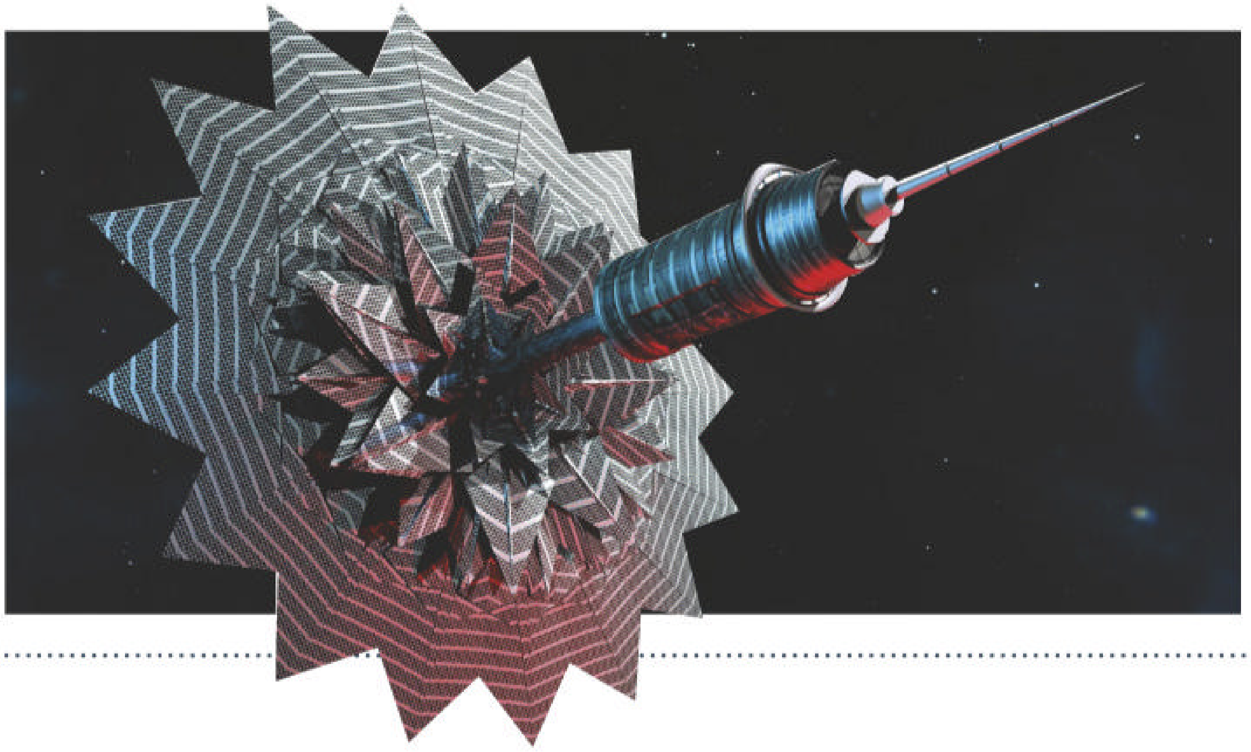
The quanta here is the Planck constant, named after Max Planck, the godfather of quantum physics. He was trying to solve a problem with our understanding of hot objects like the Sun. Our best theories couldn't match the observations of the energy they kick out. By proposing that energy is quantised, he was able to bring theory neatly into line with experiment.

2

SOMETHING CAN BE BOTH WAVE AND PARTICLE

J. J. Thomson won the Nobel Prize in 1906 for his discovery that electrons are particles. Yet his son George won the Nobel Prize in 1937 for showing that electrons are waves. Who was right? The answer is both of them. This so-called wave-particle duality is a cornerstone of quantum physics. It applies to light as well as electrons. Sometimes it pays to think about light as an electromagnetic wave, but at other times it's more useful to picture it in the form of particles called photons.

A telescope can focus light waves from distant stars, and also acts as a giant light bucket for collecting photons. It also means that light can exert pressure as photons slam into an object. This is something we already use to propel spacecraft with solar sails, and it may be possible to exploit it in order to manoeuvre a dangerous asteroid off a collision course with Earth.



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Left: As particles, light can be used to propel spacecraft through the cosmos at high speeds

3

OBJECTS CAN BE IN TWO PLACES AT ONCE

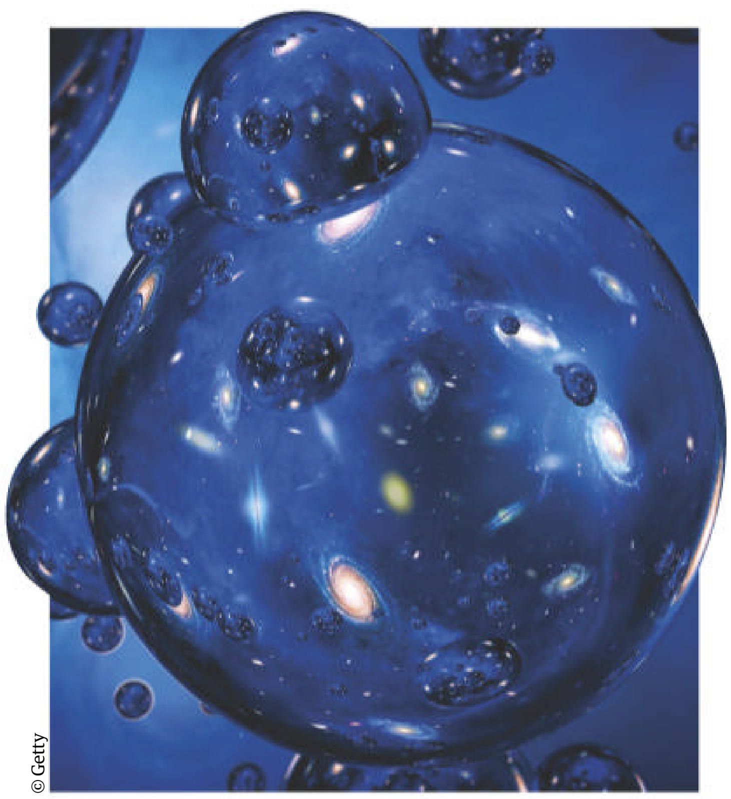
Wave-particle duality is an example of superposition. That is, a quantum object existing in multiple states at once. An electron, for example, is both 'here' and 'there' simultaneously. It's only once we do an experiment to find out where it is that it settles down into one or the other.

This makes quantum physics all about probabilities. We can only say which state an object is most likely to be in once we look. These odds are encapsulated into a mathematical entity called the wave function. Making an observation is said to 'collapse' the wave function, destroying the superposition and forcing the object into just one of its many possible states.

This idea is behind the famous Schrödinger's cat thought experiment. A cat in a sealed box has its fate linked to a quantum device. As the device exists in both states until a measurement is made, the cat is simultaneously alive and dead until we look.

4

IT MAY LEAD US TOWARDS A MULTIVERSE



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The idea that observation collapses the wave function and forces a quantum 'choice' is known as the Copenhagen interpretation of quantum physics. However, it's not the only option on the table. Advocates of the 'many worlds' interpretation argue that there is no choice involved at all. Instead, at the moment the measurement is made, reality fractures into two copies of itself: one in which we experience outcome A, and another where we see outcome B unfold. It gets around the thorny issue of needing an observer to make stuff happen – does a dog count as an observer, or a robot?

Instead, as far as a quantum particle is concerned, there's just one very weird reality consisting of many tangled-up layers. As we zoom out towards the larger scales that we experience day to day, those layers untangle into the worlds of the many worlds theory. Physicists call this process decoherence.

Left: We could just be one bubble of many, each containing a different version of a universe

Right: Erwin Schrödinger used the idea of a cat in a box to simplify superposition

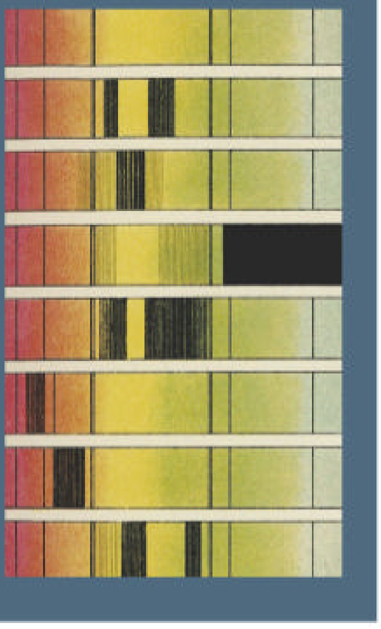
© Getty

5

IT HELPS US CHARACTERISE STARS

Danish physicist Niels Bohr showed us that the orbits of electrons inside atoms are also quantised. They come in predetermined sizes called energy levels. When an electron drops from a higher energy level to a lower energy level, it spits out a photon with an energy equal to the size of the gap. Equally, an electron can absorb a particle of light and use its energy to leap up to a higher energy level.

Astronomers use this effect all the time. We know what stars are made of because when we break up their light into a rainbow-like spectrum, we see colours that are missing. Different chemical elements have different energy level spacings, so we can work out the constituents of the Sun and other stars from the precise colours that are absent.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Left: The spectra of stars can tell us what elements they contain, giving clues to their age and other characteristics

© Getty

Right: Quantum tunnelling is the finite possibility that a particle can break through an energy barrier

6

WITHOUT IT THE SUN WOULDN'T SHINE

The Sun makes its energy through a process called nuclear fusion. It involves two protons - the positively charged particles in an atom - sticking together. However, their identical charges make them repel each other, just like two north poles of a magnet. Physicists call this the Coulomb barrier, and it's like a wall between the two protons.

Think of protons as particles and they just collide with the wall and move apart: no fusion, no sunlight. Yet think of them as waves and it's a different story. When the wave's crest reaches the wall, the leading edge has already made it through. The wave's height represents where the proton is most likely to be. So although it is unlikely to be where the leading edge is, it is there sometimes. It's as if the proton has burrowed through the barrier, and fusion occurs. Physicists call this effect 'quantum tunnelling'.

> "THEIR IDENTICAL CHARGES MAKE THEM REPEL EACH OTHER, JUST LIKE TWO NORTH POLES OF A MAGNET"

7

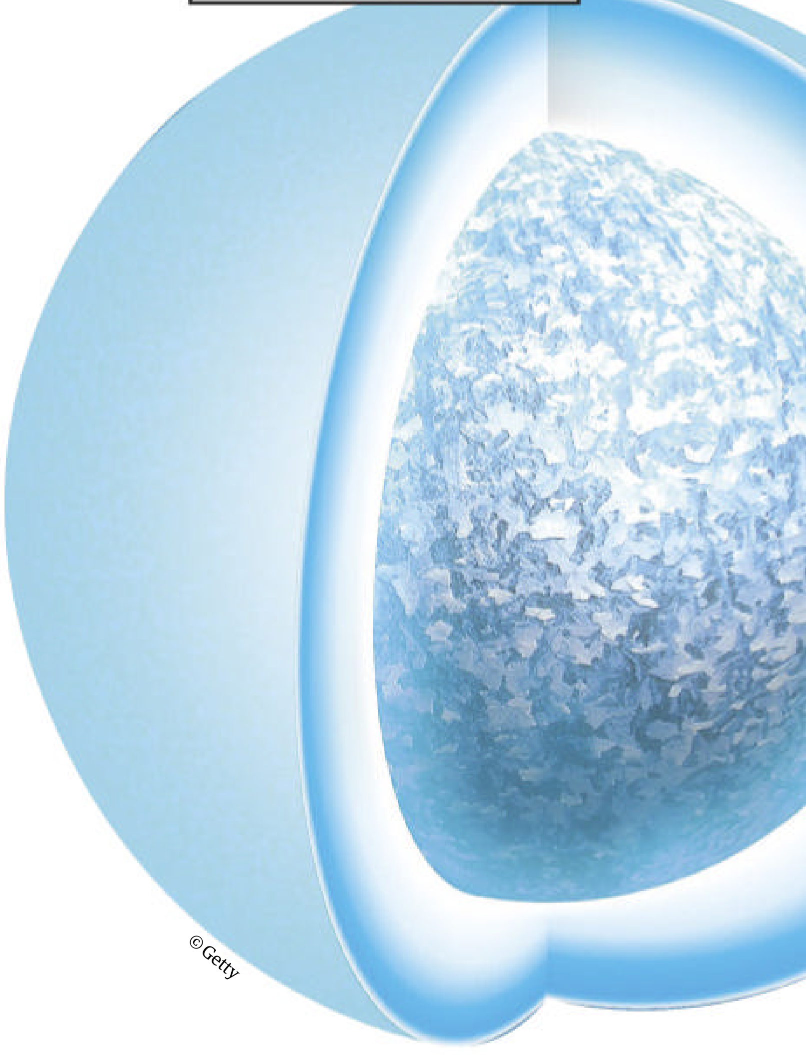
IT STOPS DEAD STARS COLLAPSING

Eventually fusion in the Sun will stop and our star will die. Gravity will win and the Sun will collapse, but not indefinitely. The smaller it gets, the more material is crammed together. Eventually a rule of quantum physics called the Pauli exclusion principle comes into play. This says that it is forbidden for certain kinds of particles - such as electrons - to exist in the same quantum state. As gravity tries to do just that, it encounters a resistance that astronomers call degeneracy pressure. The collapse stops, and a new Earth-sized object called a white dwarf forms.

Degeneracy pressure can only put up so much resistance, however. If a white dwarf grows and approaches a mass equal to 1.4 Suns, it triggers a wave of fusion that blasts it to bits. Astronomers call this explosion a Type Ia supernova, and it's bright enough to outshine an entire galaxy.

AR SCAN HERE

WATCH HOW STARS EXPLODE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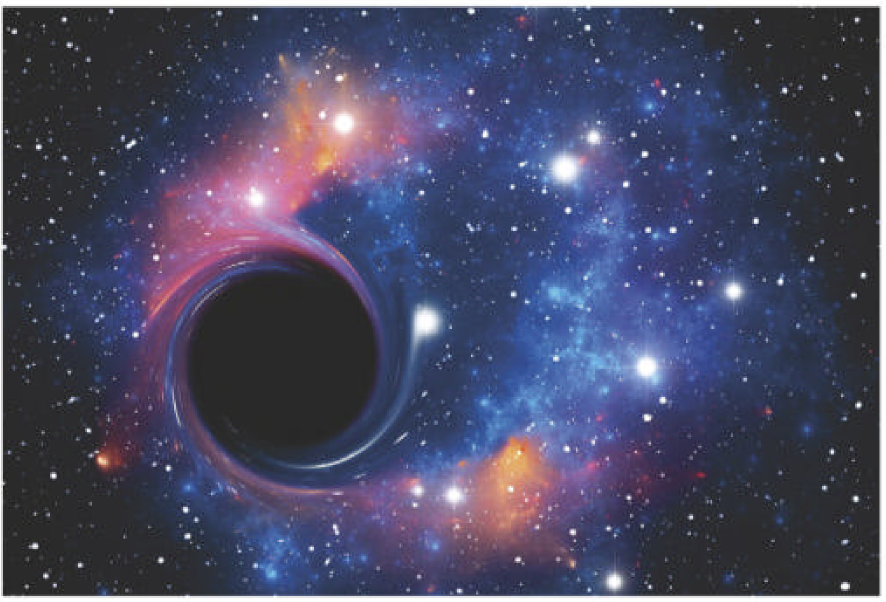
Right: It's theorised that white dwarfs' cores may crystallise as they age

8 IT CAUSES BLACK HOLES TO EVAPORATE

A quantum rule called the Heisenberg uncertainty principle says that it's impossible to perfectly know two properties of a system simultaneously. The more accurately you know one, the less precisely you know the other. This applies to momentum and position, and separately to energy and time.

It's a bit like taking out a loan. You can borrow a lot of money for a short amount of time, or a little cash for longer. This leads us to virtual particles. If enough energy is 'borrowed' from nature then a pair of particles can fleetingly pop into existence before rapidly disappearing so as not to default on the loan.

Stephen Hawking imagined this process occurring at the boundary of a black hole, where one particle escapes (as Hawking radiation) but the other is swallowed. Over time the black hole slowly evaporates, as it's not paying back the full amount it has borrowed.



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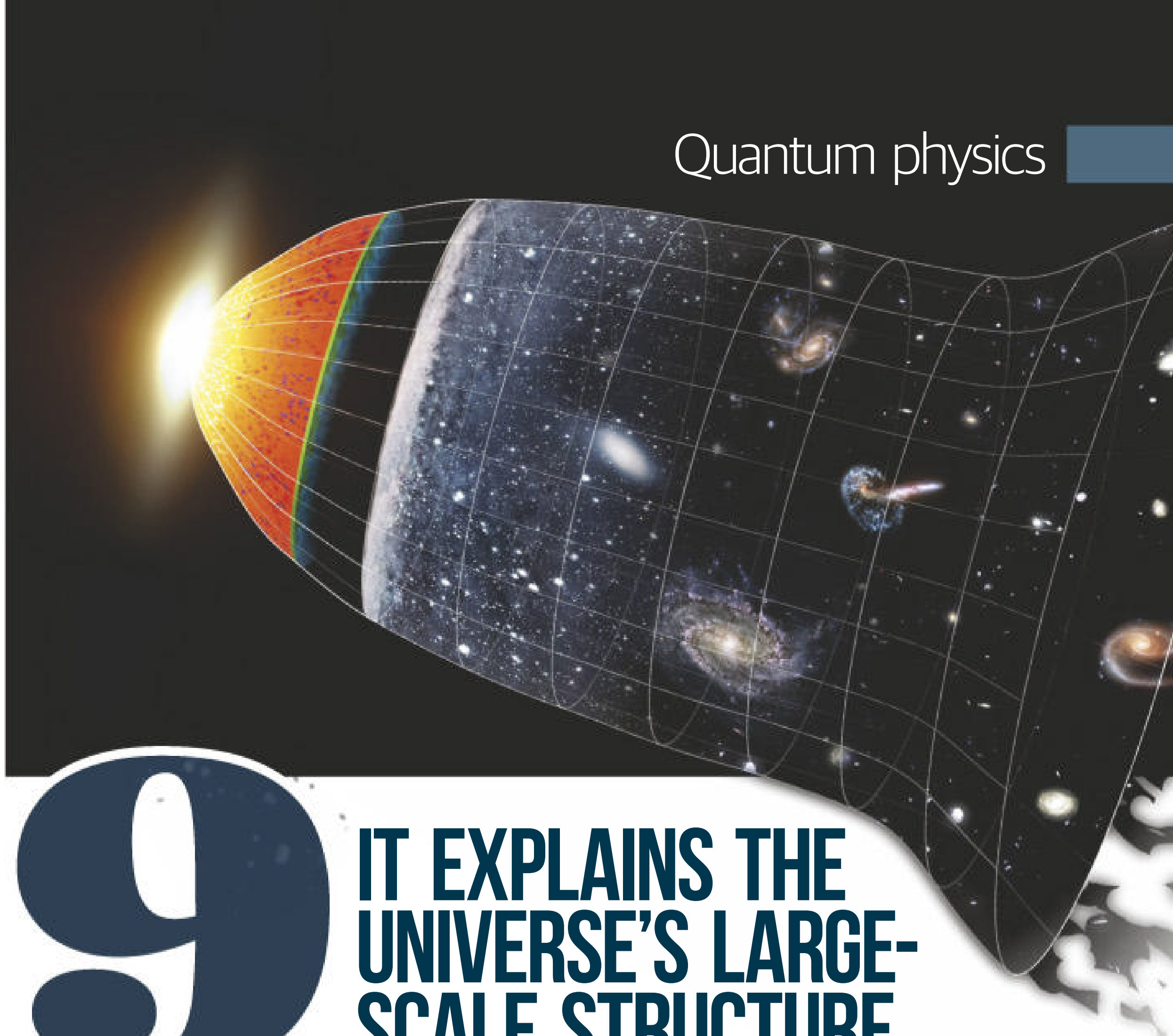

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9 IT EXPLAINS THE UNIVERSE'S LARGE-SCALE STRUCTURE

Above: Starting out as a singularity, the universe has been expanding for 13.8 billion years

Left: Not everything that falls into a black hole disappears - some matter escapes

Our best theory of the universe's origin is the Big Bang. Yet it was modified in the 1980s to include another theory called inflation. In the first trillionth of a trillionth of a trillionth of a second, the cosmos ballooned from smaller than an atom to about the size of a grapefruit. That's a whopping 10^{78} times bigger. Inflating a red blood cell by the same amount would make it larger than the entire observable universe today.

As it was initially smaller than an atom, the infant universe would have been dominated by quantum fluctuations linked to the Heisenberg uncertainty principle. Inflation caused the universe to grow rapidly before these fluctuations had a chance to fade away. This concentrated energy into some areas rather than others - something astronomers believe acted as seeds around which material could gather to form the clusters of galaxies we observe now.

10 IT IS MORE THAN A LITTLE 'SPOOKY'

As well as helping to prove that light is quantum, Einstein argued in favour of another effect that he dubbed 'spooky action at distance'. Today we know that this 'quantum entanglement' is real, but we still don't fully understand what's going on. Let's say that we bring two particles together in such a way that their quantum states are inexorably bound, or entangled. One is in state A, and the other in state B.

The Pauli exclusion principle says that they can't both be in the same state. If we change one, the other instantly changes to compensate. This happens even if we separate the two particles from each other on opposite sides of the universe. It's as if information about the change we've made has travelled between them faster than the speed of light, something Einstein said was impossible.

Right: The properties of a particle can be 'teleported' through quantum entanglement

© Getty

NANCY GRACE ROMAN SPACE TELESCOPE

Exoplanets, gravitational lenses and dark energy lurk in the infrared universe

Reported by Ian Evenden

Each time humanity launches a new space telescope, it opens up a new window to the universe. One of NASA's latest is the Nancy Grace Roman Space Telescope, previously the Wide Field Infrared Survey Telescope (WFIRST) before being renamed after NASA's first chief astronomer. It's due to launch in 2025 and will attempt to answer questions about dark energy through observations of gravitational lenses, supernovae and baryon acoustic oscillations – fluctuations in the density of the visible matter in the universe. It will also survey exoplanets, directly imaging those of Jupiter size, and use gravitational microlensing to find bodies only a few times the mass of Earth's Moon. And it will do all this using infrared light.

Roman can trace its origins back to 2011, when a 1.3-metre (4.2-foot) infrared telescope was proposed. The next year this was scrapped in favour of a plan to use two second-hand telescopes donated by the National Reconnaissance Office (NRO), a US intelligence agency that also uses space telescopes, but points them in the other direction. The NRO considers these telescopes obsolete for its purposes, but for NASA they're a way to continue with space science in an era of strained budgets, where the $10 billion (£7.2 billion) cost of the James Webb Space Telescope is starting to raise a few eyebrows. Michael Moore, the agency's acting deputy director for astrophysics, has stated that using both telescopes may ultimately save NASA $1.5 billion (£1.1 billion) in the long term.

Roman was earmarked for cancellation itself in the 2019 US budget proposal due to the higher priority of Webb, but this was rejected by Congress and the mission continued, and should now cost no more than $3.9 billion (£2.8 billion). While the NRO telescopes, constructed between the late 1990s and early 2000s, are structurally intact and have never been used, they've been stripped of all their electronics, so these will need to be replaced at NASA's cost. Their 2.4-metre (7.9-foot) primary mirrors are

© NASA, ESA

Left: Galaxy cluster MACS J1206.2-0847, 4.5 billion light years from Earth, distorted by gravitational lensing as seen through the Hubble Space Telescope

“IF YOU’RE INTERESTED IN THE MAJORITY OF STARS IN THE LOCAL UNIVERSE, THE BEST PLACE TO LOOK FOR THEM IS IN THE INFRARED” DAVID CLEMENTS

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ROMAN VS HUBBLE

© NASA

Nancy Grace Roman Space Telescope

Launching: 2025

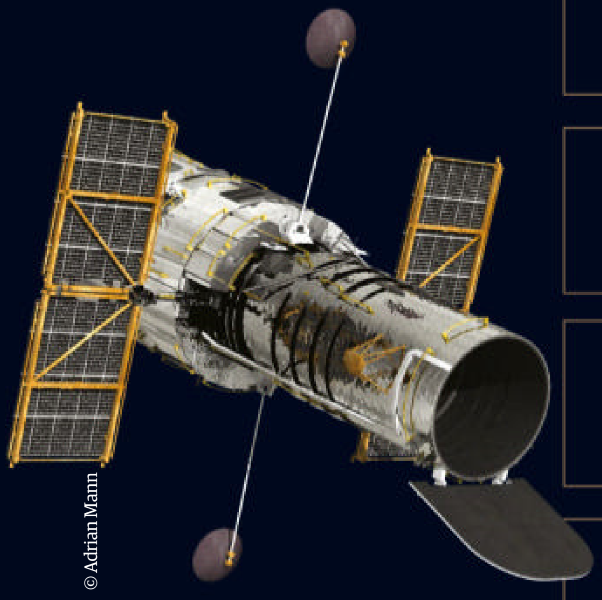
Weight: 4,166 kilograms

Field of view:
0.28 square degrees

Type of telescope:
Three-mirror anastigmat

Wavebands:
Near-infrared, visible light

What it will do: Study the far universe for evidence of expansion due to dark energy, and nearer stars for exoplanets through gravitational lensing. It will directly image closer stars for the first images and spectra of their giant planets.



© Adrian Mann

Hubble Space Telescope

Launched: 1990

Weight: 11,110 kilograms

Field of view:
0.0561 square degrees

Type of telescope:
Ritchey-Chrétien reflector

Wavebands: Near-infrared, visible light, ultraviolet

What it's done: Made discoveries both inside and outside the Solar System. It's measured cosmic distances more accurately than ever before and helped prove that black holes are common at galactic centres.

> “THE SHORTER FOCAL LENGTH OF THE TELESCOPES MEANS THEY HAVE A WIDER FIELD OF VIEW, IMAGING ABOUT 100 TIMES THE AREA HUBBLE CAN”

still attached, however, and are the same size and quality as those within Hubble, though the shorter focal length of the telescopes means they have a wider field of view, imaging about 100 times the area Hubble can. The mirror is so finely polished that the average bump on its surface is only 1.2 nanometres tall. If scaled to the size of Earth, those bumps would rise to just over half a centimetre. The mirror and some parts for a third telescope also exist, but NASA currently only has firm plans to use one of them, though the idea of sending the other to Mars to photograph the surface in high detail has been floated.

Aboard Roman will be two instruments: the Wide-Field Instrument, a 300-megapixel camera that captures light in visible and near-infrared wavelengths, and a coronagraph dedicated to studying distant stars in infrared. A system of prisms, masks and mirrors allows it to block out the glare from a star, essentially placing a dark spot over it, to reveal planets in orbit.

“What we're trying to do is cancel out a billion photons from the star for every one we capture from the planet,” says Jason Rhodes, project scientist for Roman at NASA's Jet Propulsion Laboratory in Pasadena, California. “This may be the most complicated astronomical instrument ever flown. With [Roman] we'll be able to get images and spectra of these large planets, with the goal of proving technologies that will be used in a future mission to eventually look at small rocky planets that could have liquid water on their surfaces, or even signs of life, like our own.”

To do this, Roman will orbit at a point known as Lagrange point 2 (L2). This is a spot 1.5 million kilometres (932,000 miles) from Earth in the opposite direction to the Sun where gravitational forces cancel out and objects will naturally hold their position relative to the large bodies. This point is four times as far from Earth as the Moon orbits, and will be shared with other space observatories, including Webb.

One benefit of L2 is that much of the Sun's radiation is blocked by the Earth, appearing in a constant state of partial eclipse, and therefore the observatory is able to maintain a constant temperature while absorbing solar energy. It's also extremely stable. Hubble, by comparison, sits in low-Earth orbit only 547 kilometres (340 miles) above our planet, and due to atmospheric drag is expected to re-enter the atmosphere between 2028 and 2040.

The first coronagraph in space – and still the only one at the time of writing – is on Hubble.

NASA'S FIRST CHIEF ASTRONOMER,
THE MOTHER OF HUBBLE

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© NASA

Right: A biography of, and interview with, Nancy Roman, chronicling her passion for astronomy at school to Apollo 11 and the planning of the Hubble Space Telescope

After Roman launches, however, there will be three: Webb, due to blast off in 2021, will have one too, but it lacks the starlight-suppression technology of Roman. When it comes to discovering exoplanets, Roman has two methods available. The first is gravitational microlensing, which occurs when a star passes in front of another, its gravity bending the light from the farther star and magnifying it. Planets orbiting the closer star can have the same effect, just on a smaller scale, and the telescope should be sensitive to planets as small as Mars. For more distant stars, Roman should be able to find large planets in close orbits - like so-called hot Jupiters - and even the failed stars known as brown dwarfs. Rather than the dip in brightness associated with a planet when using the more common transit method of detection, a microlensing exoplanet actually causes its star to appear brighter, with peak brightness achieved when the foreground and background stars are perfectly aligned.

Above: Hubble is able to image Solar System planets in great detail, but can't do the same for exoplanets

© NASA/ESA

Right: Roman is being prepared for a 2025 launch, led by a team at NASA's Goddard Space Flight Center

© Harris Corporation / TJT Photography

A CLOSER LOOK AT ROMAN'S WIDE-FIELD INSTRUMENT (WFI)

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ANATOMY OF NASA'S ROMAN SPACE TELESCOPE

1 Solar array and sunshield
This will generate power, as well as keeping sunlight out of the telescope's aperture.

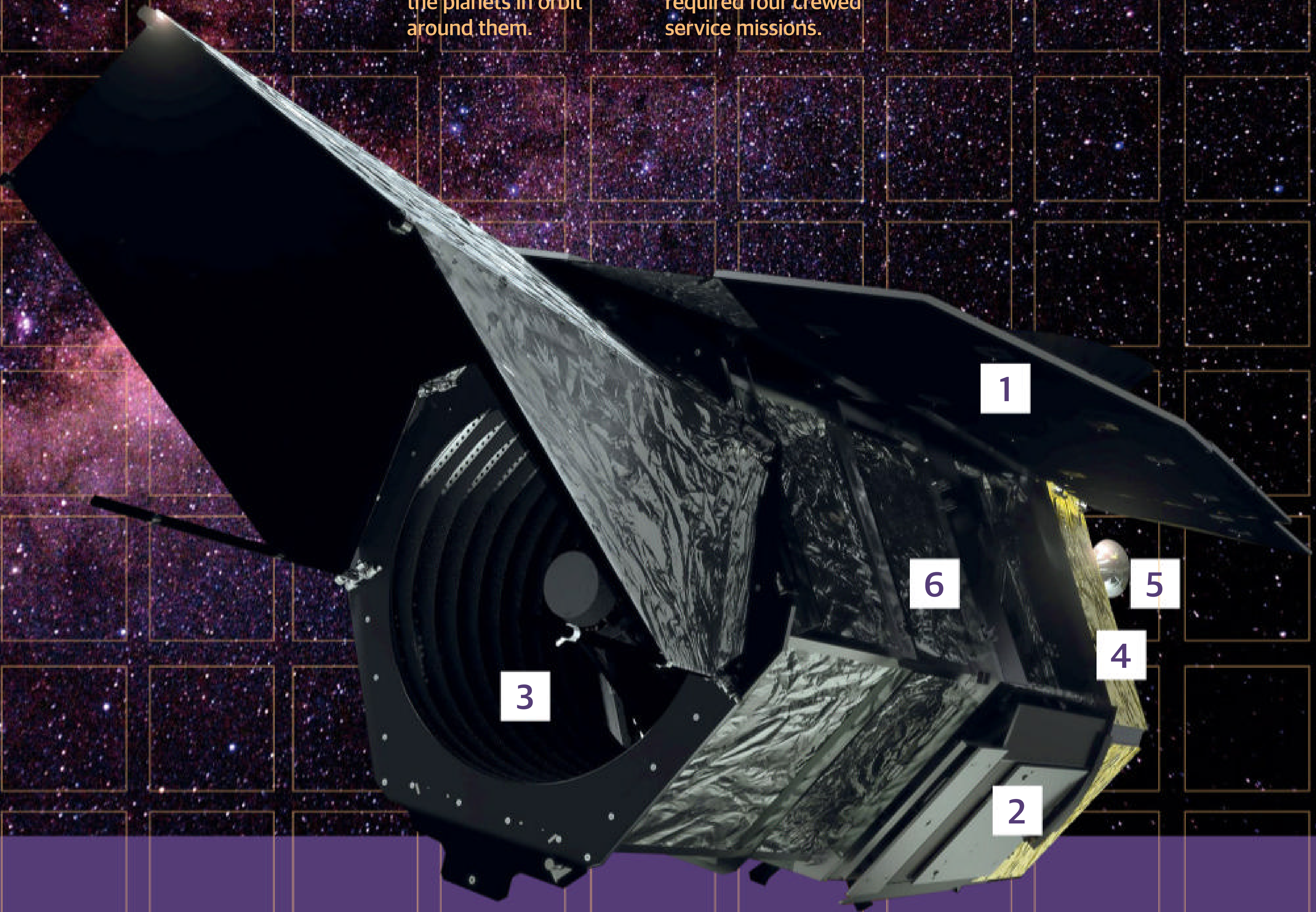
2 Wide-Field Instrument
The 300MP camera that's at the heart of the Roman mission.

3 Coronagraph instrument
On the opposite side to the WFI, this instrument blocks out light from nearby stars to reveal the planets in orbit around them.

4 Serviceable in space
The observatory is designed to be serviceable by robots, unlike Hubble which has required four crewed service missions.

5 High-gain antenna
This will be used for sending huge amounts of data back to Earth.

6 Outer barrel assembly
The shape of the telescope is designed to deflect sunlight away from the detectors.



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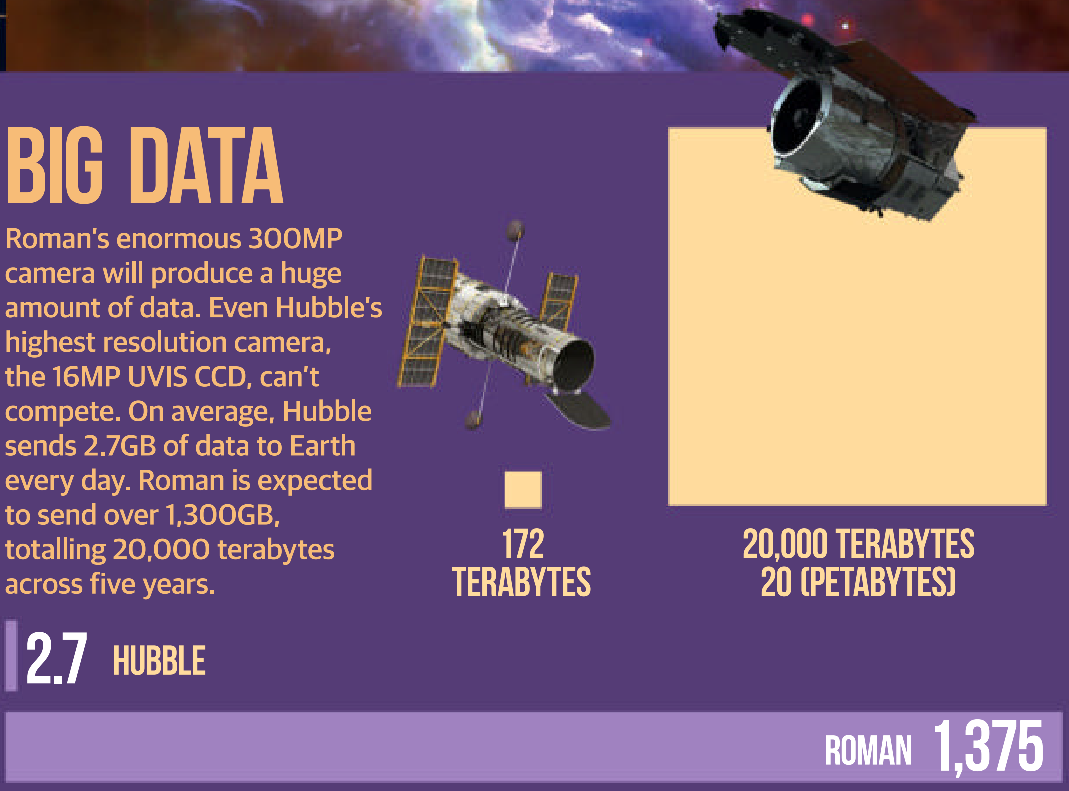
BIG DATA

Roman's enormous 300MP camera will produce a huge amount of data. Even Hubble's highest resolution camera, the 16MP UVIS CCD, can't compete. On average, Hubble sends 2.7GB of data to Earth every day. Roman is expected to send over 1,300GB, totalling 20,000 terabytes across five years.



© Harris Corporation / TJT Photography

Above: Roman will be able to reveal more of the universe, working alongside Hubble and Webb to show us stunning sights

Left: The outer barrel of the telescope under construction at Harris Corporation

Roman's detectors are tuned to light in the infrared part of the spectrum, but just why do astronomers want to look there? Dr David Clements, a reader in astrophysics at Imperial College London who studies the universe in the far-infrared, explains: "The infrared stretches all the way from one micron in wavelength to about a millimetre, so that's a huge chunk of the electromagnetic spectrum. It gives us access to things that you can't see from the ground. Starlight is a thermal emission, and if you take a star like our Sun, with a surface temperature of around 5,800 Kelvin, its emission spectrum peaks, as if by coincidence, at about the wavelength our eyes are most sensitive to. And the atmosphere is transparent at those wavelengths too.

"If you're interested in things that are cooler than the Sun - such as late-type stars, M stars [red dwarfs] and brown dwarfs - then their peak emissions are at longer wavelengths," Clements continues. "The majority of stars in our galaxy, and other galaxies, are M stars with a temperature of a few thousand Kelvin. Their black-body spectrum - and in fact the black-body spectrum of the average galaxy - peaks at a wavelength of about 1.6 microns. If you're interested in the majority of stars in the local universe, the best place to look for them is in the infrared."

And it's important that these observations take place in space, too. "Trying to do mid-infrared astronomy from the ground is like trying to do optical astronomy with a telescope and a building that are glowing red hot," says Clements. "That mid-infrared band is known as the thermal infrared, and everything there is glowing as if it's been in a furnace. And that's also true of the atmosphere. It can be done, but it's very, very hard. In the far-infrared the background problem is even worse - there's no point doing it from the ground because the atmosphere is opaque at those wavelengths. That's why we build telescopes like Herschel and Planck to get above the atmosphere to do anything at all."

Then there's the problem of obscuration. "Star formation takes place in clouds of gas, and where you've got gas, you've got dust. Dust absorbs starlight as a function of wavelength, just as there's dust and smoke in our atmosphere that gives you the red Sun as it goes down - it absorbs short wavelengths better than long ones. If you want to see what's going on in a region that's got lots of dust, you can't do that in the optical because there's too much obscuration, so you look in the near-infrared. If you want to go to a region like the hearts of galaxies that are forming stars at an extremely high rate, you have to go into the far-infrared."

There's also redshift to consider. "Look at things that are farther and farther away," says Clements, "and the whole spectrum is shifted to longer wavelengths. The most prominent emission line from any galaxy that's got emission lines is the Lyman-alpha line of hydrogen. At zero redshift that's way into the ultraviolet, but by the time you look at a quasar with a redshift of six you're into the photographers' infrared, and if it redshifts still further you're into the astronomers' near-infrared. And that's true for every emission line down to hydrogen-alpha. H-alpha at a redshift of one is 1.3 microns in wavelength, so you're into the infrared in the relatively local universe."

With simple distance pushing many potential targets into Roman's sensitivity band, there's certainly a lot for it to look at. Another part of its mission, however, is to observe the effects of something we can't see. Sensitive enough to detect infrared light from farther away than any other telescope, it will show the universe in its early stages, helping to unravel how it has expanded over the past 13.8 billion years and how it will continue to evolve. "We're going to try to discover the fate of the universe," says NASA's Jeffrey Kruk, a Roman project scientist. "The expansion of the universe is accelerating, and one of the things the Wide-Field Instrument will help us figure out is if the acceleration is increasing or slowing down."

One potential driver of the expansion is dark energy, the mysterious substance that makes up about 70 per cent of the total content of the cosmos, which may also be changing as the universe evolves. Roman will measure millions of distant galaxies to show how matter is distributed across the universe. Widely thought to be constant, dark energy was shown to have possibly varied over time thanks to data from the Chandra X-ray Observatory. It's an exciting time to be chasing this invisible driver of change.

A disused spy satellite getting a second lease of life as an observatory that gives scientists a new viewpoint on the cosmos? It's a story that will only get better as Roman sends back pictures of the universe to rival those of Hubble - and it may help to crack one of the universe's final, most enduring, mysteries, too.

> "LOOK AT THINGS THAT ARE FARTHER AND FARTHER AWAY AND THE WHOLE SPECTRUM IS SHIFTED TO LONGER WAVELENGTHS" DAVID CLEMENTS

Ian Evenden
Space science writer
Ian has been writing about the universe for over ten years, focusing on cosmology and space exploration. He's also a keen astrophotographer.

GET TO KNOW ROMAN'S CORONAGRAPH INSTRUMENT

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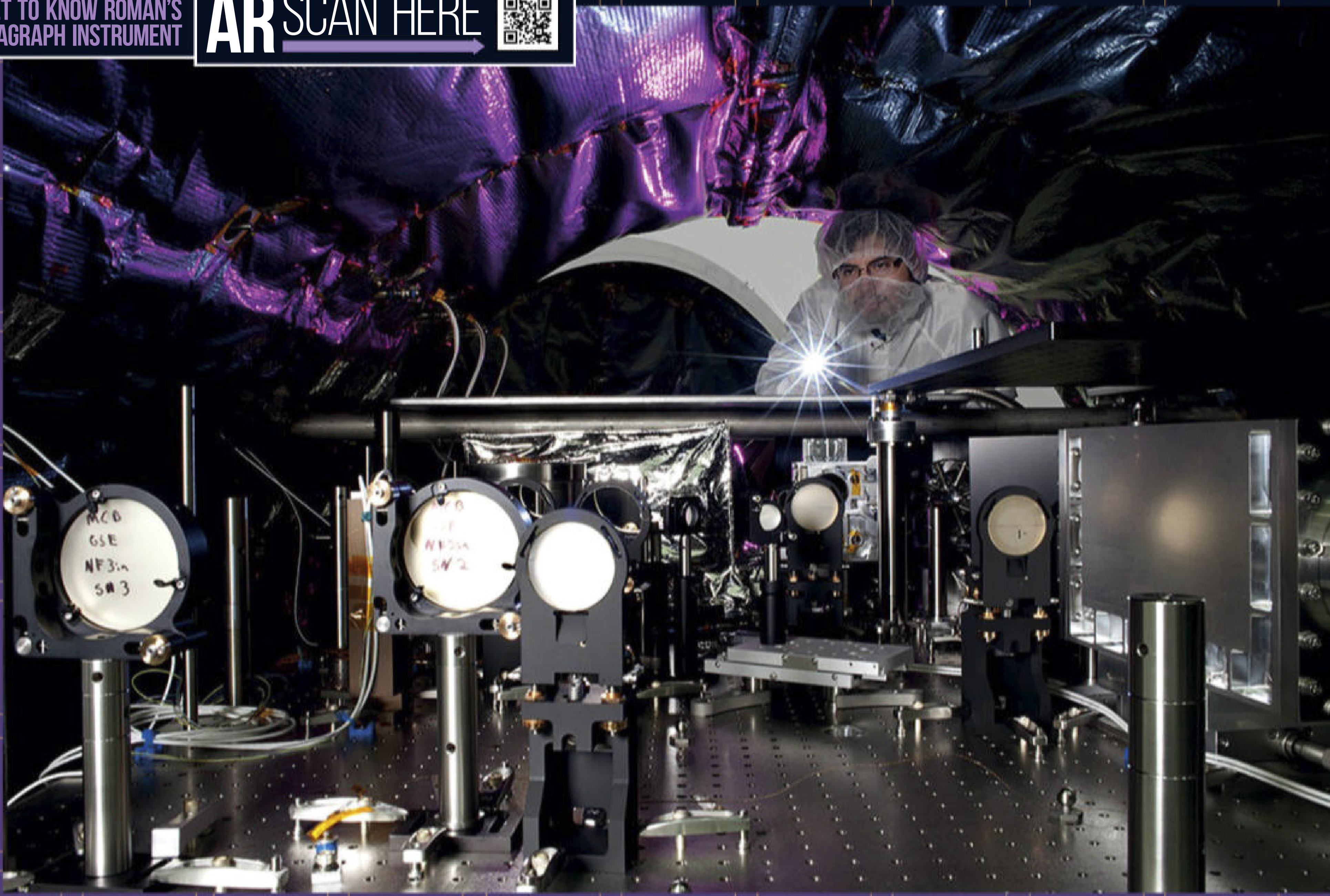
Right: An optical engineer at NASA's Jet Propulsion Laboratory shines a light on the interior of a testbed for the coronagraph that will fly aboard the Roman Space Telescope



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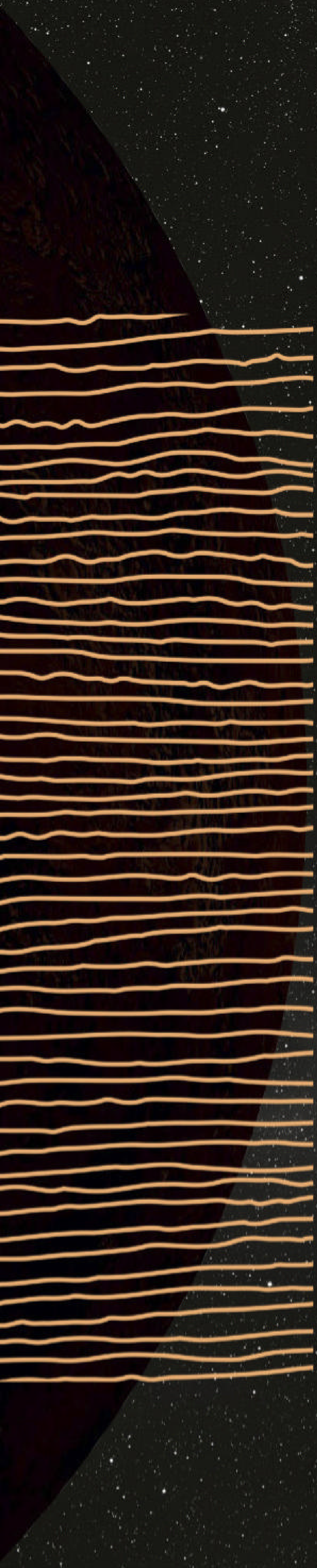
MYSTERIES OF THE UNIVERSE

WHY IS MARS CONTINUING TO WOBBLE?



© Alamy; Getty

Researchers confirm that the Red Planet is spinning off its axis

Reported by David Crookes

Grab your telescope and gaze at Mars. Are you able to spot something unusual as you focus in on the planet, paying particular attention to its white caps? Not even a little bit? Here's a clue: we're referring to a teeny, tiny wobble that occurs as the poles wander from the Red Planet's axis of rotation. Still can't see it? Don't worry - it's taken scientists decades to spot some rather odd behaviour on the Red Planet.

For the past 18 years, radio tracking observations determined from satellites orbiting the planet have been able to show stark evidence of the Chandler wobble on Mars - a variation of latitude named after American astronomer Seth Carlo Chandler, who discovered the phenomenon in 1891. In simple terms, it means the Red Planet is repeatedly wobbling as it spins, in this case by just ten centimetres (four inches) from the planet's axis of rotation - that's why you're unlikely to see it for yourself. If you're after a nailed-on explanation of why it's continuing to happen, then you're sadly out of luck.

Although scientists have made a breakthrough in determining that the Red Planet wobbles in its rotation, they are not exactly sure what is driving it. What they've gleaned from studying the data so far is that the Chandler wobble on Mars occurs in a near-circular, counterclockwise direction, as viewed from its north pole, every 207 days. As a result, the poles don't always line up perfectly. The Red Planet is the only other body in the universe known to exhibit such behaviour, with the phenomenon only ever discovered and confirmed on Earth before.

It makes the new discovery highly significant, and not just because there are now two planets resembling a spinning top teetering as it loses speed. This latest study shows the sheer importance of gathering and analysing information over a long period of time - a laborious process requiring heaps of patience, but one that has proven ultimately rewarding.

"With 18 years of data, the Chandler wobble signal is very clear," explains Alex Konopliv, an aerospace engineer at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California. And as more data comes through, the better the conclusions will become.

Before we take a closer look at the Chandler wobble on Mars, let's first briefly examine its effect on Earth by way of comparison. We know that our planet rotates on its axis every 24 hours - every 23 hours, 56 minutes and four seconds, to be exact - but while you may excitedly spin a globe on your desk and smoothly reach a destination when it comes to a halt, real life isn't quite like that.

> "WITH 18 YEARS OF DATA, THE CHANDLER WOBBLE SIGNAL IS VERY CLEAR"
>
> ALEX KONOPLIV

CHANDLER WOBBLE BY NUMBERS

10

Amount Mars' poles wander in centimetres

207

Repeated cycle of the Chandler wobble on Mars in days

18

Years of data taken to determine the Chandler wobble on Mars

NINE

Maximum off-centre motion, in metres, of the Chandler wobble on Earth

433

Repeated cycle of the Chandler wobble on Earth in days

TWO

Number of planets confirmed to exhibit signs of the Chandler wobble

1891

Year the Chandler wobble was discovered

63

Maximum number of years the wobble should take to freely decay if not excited

On Earth, the poles repeatedly wander away from the average axis of rotation by as much as nine metres (30 feet) every 433 days. We don't feel it, of course, and the only downside is that the wobble needs to be considered when observing Earth or working with GPS. But one thing is certain: it is much more perceptible than the very slight wobble discovered on Mars, so how did the scientists reach their conclusion given such circumstances?

The answer comes in the form of NASA satellites, which have been orbiting Mars for different reasons. The Mars Global Surveyor, for instance, was used to map the entire planet between 1999 and 2006. Mars Odyssey has been seeking evidence of water and ice while studying the planet's geology and radiation environment since 2001. And the Mars Reconnaissance Orbiter has been looking for potential future landing sites since 2006.

Konopliv tells **All About Space** that researchers have been able to collect enough precise information from these satellites to calculate the effects of gravitation on the orbits of the spacecraft. They've determined the pole motion from radio tracking observations, and it's led to a better understanding of the planet. "The Chandler wobble was detected because it affects the orbit of spacecraft at Mars," Konopliv affirms. "It mostly causes a slight oscillation of the orbital plane of a spacecraft with a period of a Mars day."

The method has been detailed in a study recently published by the American Geophysical Union in its peer-reviewed scientific journal, *Geophysical Research Letters*. "The size of the oscillation changes slowly over the months and years, and we see it as a time-varying signature in the Mars gravity field," Konopliv continues.

"THE CHANDLER WOBBLE AFFECTS THE ORBIT OF SPACECRAFT AT MARS"

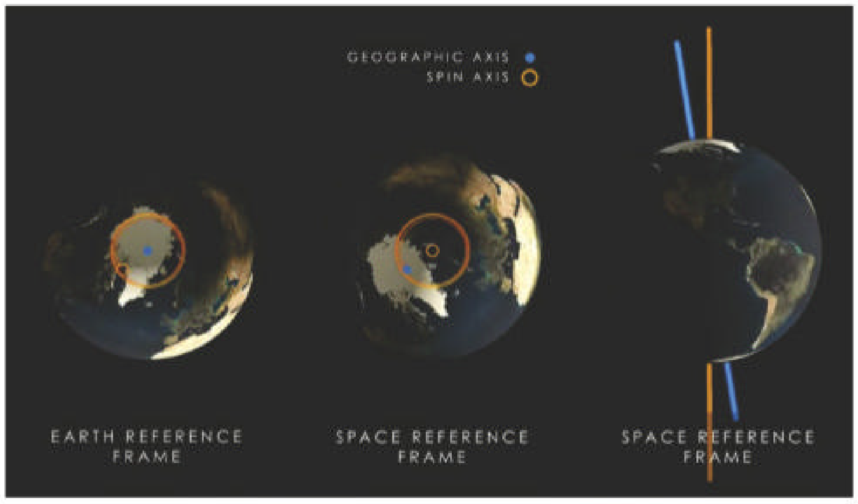
ALEX KONOPLIV

"This signature is detected using Doppler tracking data of the spacecraft from the NASA Deep Space Network of stations. [It measures the spacecraft's speed along the direction from Earth's tracking station to the spacecraft.] Those measurements help us determine the spacecraft's orbit and how it changes over time."

Since the signal is incredibly small, and changes so slowly over time, having many years of highly accurate data has proved vital in the wobble's detection. "Additionally, there are other time-varying signatures in the gravity field that must be separated from the Chandler wobble signal," Konopliv says.

"These other signatures are due to the seasonal melting of the polar ice caps and the resulting movement of mass between the north and south poles. Our previous attempts with less data to detect the Chandler wobble were unsuccessful because we could not distinguish between the mass movement and the wobble."

Below: You can see here that the geographic and spin axes of Earth do not always match up, indicative of the Chandler wobble. The axes only match once every 6.4 years



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Right: The amount of data amassed over 18 years ensured scientists could distinguish a wobble intrinsic to Mars' shape and interior from those potentially caused by outside factors

© NASA

HOW MARS WOBBLES LIKE A SPINNING TOP

1 Axis of rotation

Mars rotates around its axis every 24 hours, 39 minutes and 35 seconds, which is slightly longer than on Earth, where the rotation takes 23 hours, 56 minutes and four seconds. This time defines a day on Mars, called a sol.

2 Mars' tilt

Mars is tilted 25.2 degrees relative to the plane of the Red Planet's orbit around the Sun. Because this is close to the 23.5-degree tilt here on Earth, it experiences similar seasons.

3 A small wobble

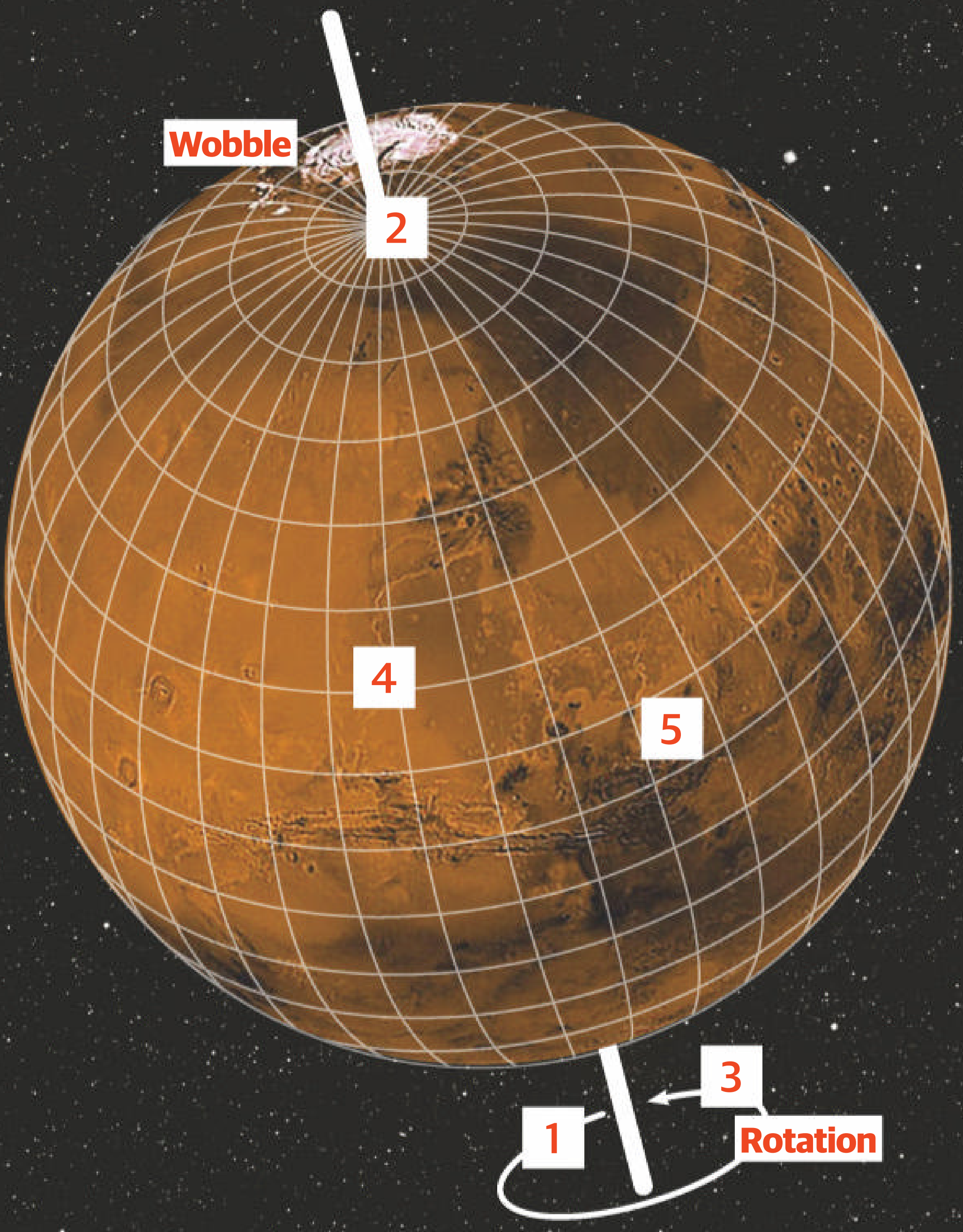
The wobble is only slight. It has an amplitude of ten centimetres (four inches) on the surface. When viewed from the north pole, it's in a near-circular counterclockwise direction.

4 Time taken

The wobble will complete its full circular deviation every 206.9 days, plus or minus half a day – a cycle that should, if no external moment is applied, die down with a time constant of between 7 and 63 years.

5 External interference

The fact Mars – which like Earth is not a perfect sphere – continues to wobble means it is being re-excited. This is likely due to atmospheric pressure changes.



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But why does Mars wobble in the first place? Like Earth, which is 0.3 per cent thicker in the middle, the Red Planet – which is 0.6 per cent thicker – is not a perfect sphere, leading to imbalances that have an impact on both of these planets' spin. As such, it's determined that the Chandler wobble happens on planets that are not perfectly round, and this is why the phenomenon has long been thought to take place on planets other than Earth. It's just that scientists have not had firm evidence.

In the case of Mars, the spinning is understood to have begun due to seasonal atmospheric changes caused by the melting of the polar ice caps. If left alone, however, a planetary wobble of this nature should slow down over time. "The time to die down on Mars is the range of 7 to 63 years," Konopliv says, but that is not happening. So why is that?

For Earth, past studies suggest the excitation of the wobble is likely due to pressure changes in the atmosphere combined with oceanic processes, keeping things moving. In 2000, for example, JPL geophysicist Richard Gross said that fluctuating pressure at the bottom of the ocean – which is caused by temperature and salinity changes – was the principal cause, along with wind-driven changes in the circulation of the ocean.

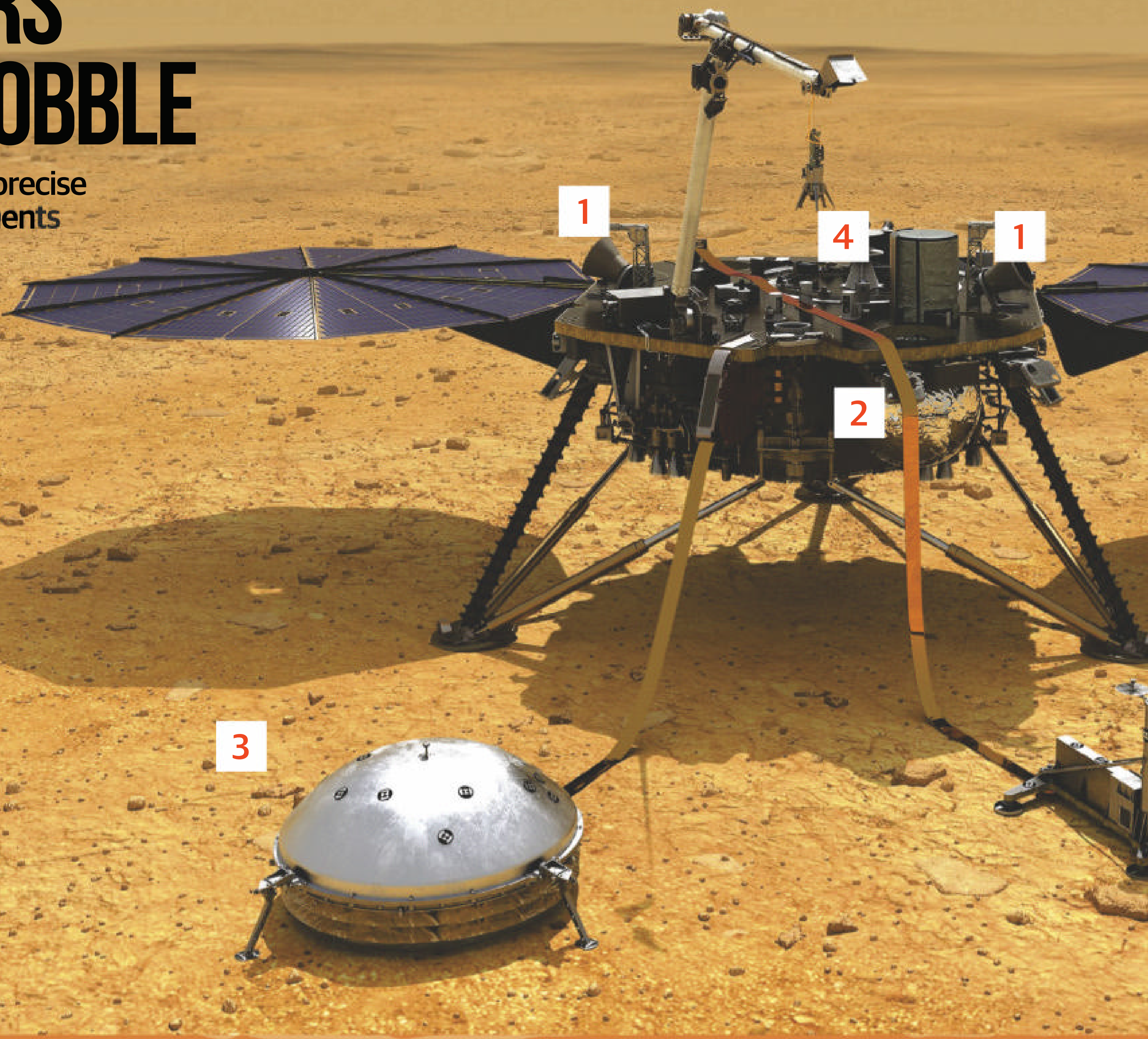
"The Chandler wobble of Earth is mainly excited by the oceans and the atmosphere," affirms Belgian geophysicist Véronique Dehant. Yet Mars does not have oceans, so could other external factors help explain the excitation? Maybe it's due to the polar ice caps melting…

Konopliv thinks not. He says that the seasonal melting and reforming of the polar ice caps is an annual signal that is nearly repeatable. Taking into account that a Mars year is 687 days and a Chandler wobble period is 207 days, Konopliv says the wobble is shown to take place 3.3 times a year.

Right: The Mars Global Surveyor completed its mission in 2006 when it became unresponsive to messages and commands, but it was still able to provide radio tracking observations of the Red Planet

DETECTING MARS' NORTH POLE WOBBLE

The InSight mission seeks to provide precise measurements of the planet's movements



1 The RISE antennae
Two medium-gain horn antennae are on the deck of the InSight Mars lander. Radio signals are used to measure the tiny wobble in the rotation of the planet over time as it orbits the Sun.

2 Radio science equipment
RISE – standing for Rotation and Interior Structure Experiment – also includes an X-band radio transponder and a transmitter inside the lander, where they are shielded from the harsh Martian environment.

3 Gathering information
The RISE radio science experiment tracks the location of the lander. The wobble indicates the nature of Mars' core – molten-liquid metal or solid metal – and will also determine the presence of other elements on the Red Planet besides iron.

4 Back and forth
The signal sent to the lander from Earth is sent back via the Deep Space Network. Any changes to the returned signal – the 'Doppler shift' – not only reveal the exact location of the lander down to a few centimetres, but the extent of any wobble.

SEE HOW INSIGHT TOUCHED DOWN ON MARS

AR SCAN HERE

As a result, any mass signatures from melting polar caps would show exactly one, two, three or four times a year, and would be distinctly different from the wobble. "That is the reason why an extensive dataset is needed, because we've been able to separate the Chandler frequency from any third-annual signature," Konopliv says.

That just leaves pressure changes as the primary cause of the ongoing wobble. "For Mars, the principal excitation is likely of atmospheric origin," Konopliv explains. And yet the issue could still run deeper, with the motion driven by the properties of Mars' mantle, something which is being explored by Dehant. "To be detectable, the Chandler wobble requires the presence of a continuous forcing at a period close to that of the wobble," recaps Dehant. "The wobble of Earth is mainly excited by the oceans and the atmosphere, and for Mars, which doesn't have oceans, atmospheric processes are the main driver.

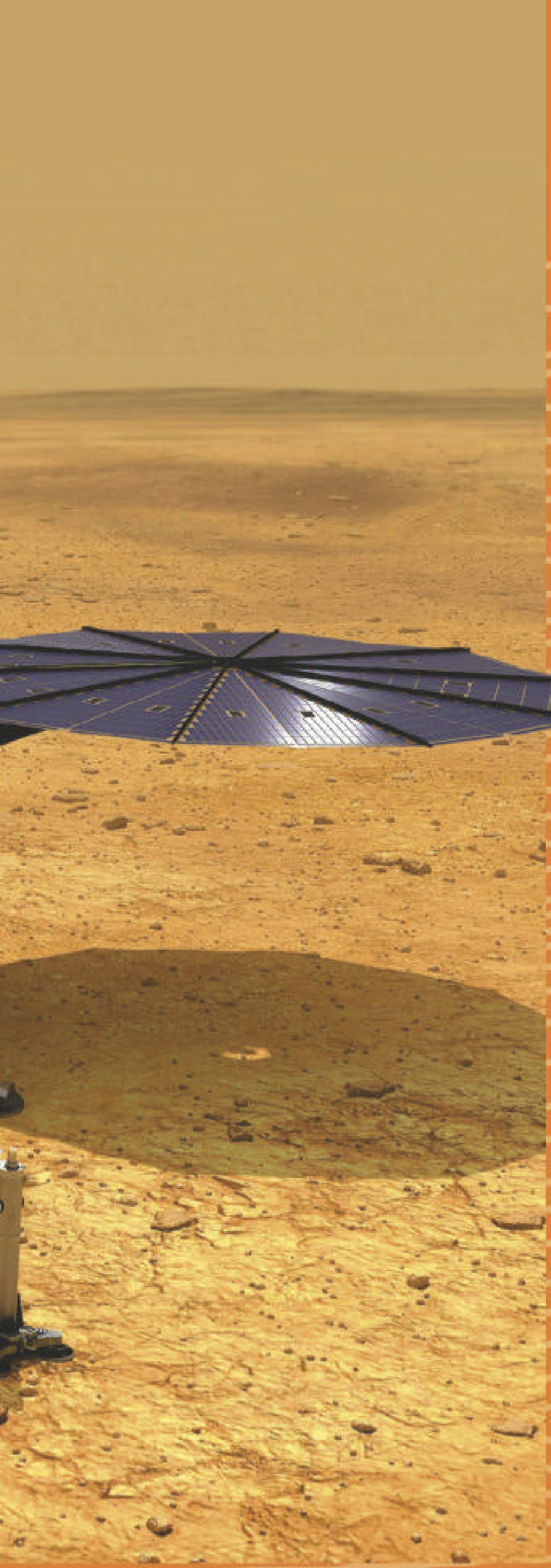
"Without forcing, the wobble would decay away after less than 100 years for Mars and about 350 years for Earth, so the Chandler wobble could also be excited by internal processes, like planetary quakes or flows in the liquid core. Measuring the Chandler wobble on different planets therefore provides not only knowledge about the forcing processes and material properties, but also insights into comparative planetology."

Whatever the cause, the wobble is providing fresh insights into the interior of Mars, notably its material properties and thermal state. By assessing the amount of time it takes for the pole to complete a wobble cycle, scientists learn the extent to which the Red Planet's mantle can deform.

"The deformations of the Martian mantle mainly depend on its rigidity, and the rigidity is strongly dependent on temperature," Attilio Rivoldini, a physicist at the Royal Observatory of Belgium, tells **All About Space**.

"By measuring the Chandler wobble period, we can deduce information about the thermal state because we have a good knowledge about the rigidity of candidate Mars mantle materials. This knowledge has mainly been acquired by studying the composition of Martian meteorites and by

> "THE DEFORMATIONS OF THE MANTLE DEPEND ON RIGIDITY, AND THE RIGIDITY IS STRONGLY DEPENDENT ON TEMPERATURE" ATTILIO RIVOLDINI



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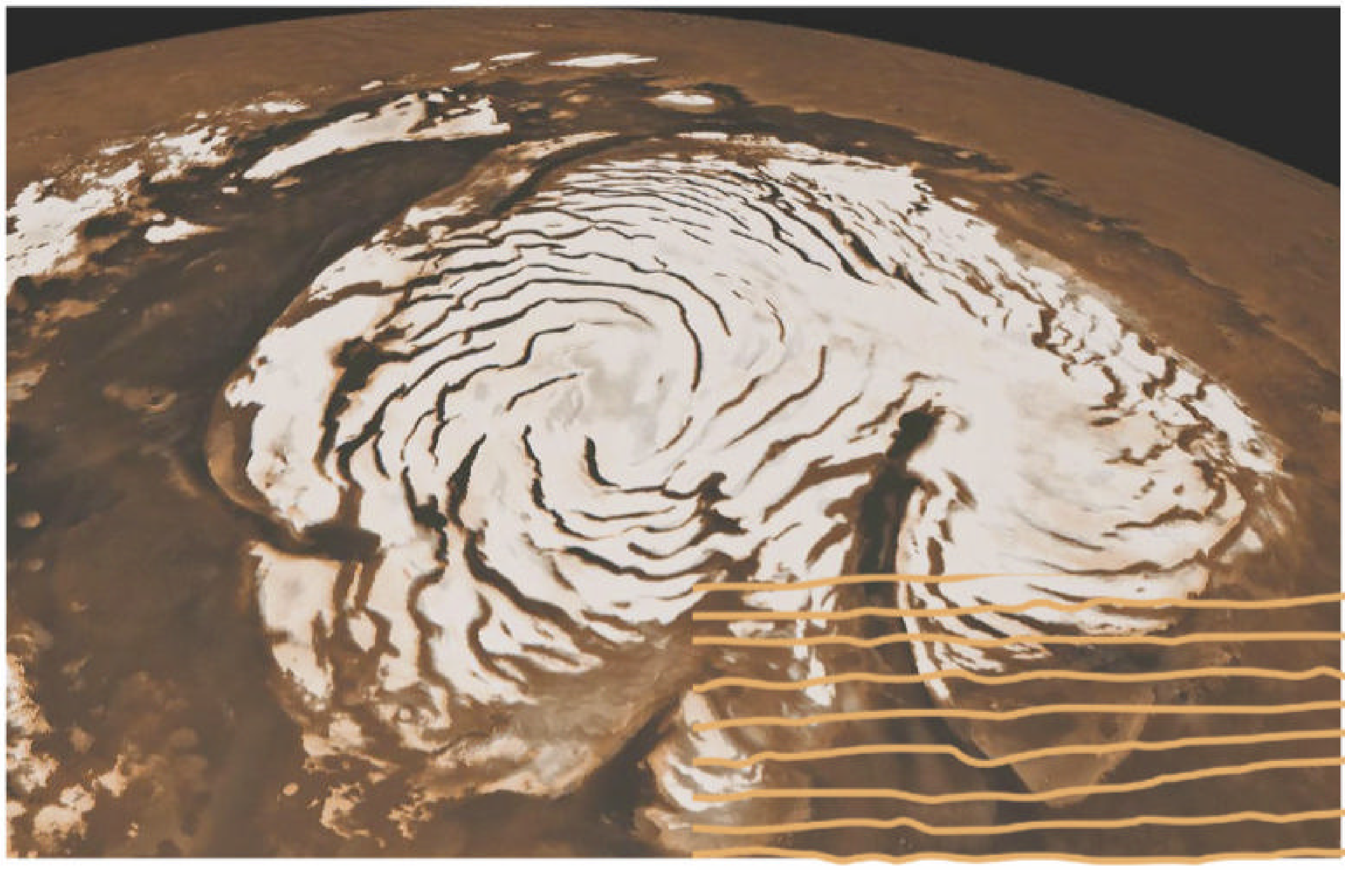
performing laboratory experiments about the material properties of candidate materials."

The wobbling of Mars has certainly piqued the interest of scientists, and further studies are sure to be carried out over the years. New knowledge about the planet's temperature and composition is vital in gaining a better picture of the planet, and Dehant is among those at the forefront of future missions.

"I think the next study of interest will be the measurement of the Mars nutation from the InSight mission," says Dehant. "Nutations are periodic changes in the orientation of the planet, mainly due to the gravitational interaction with the Sun, and the amplitude of the nutations depends on a well-known forcing and on the interior structure of Mars, in particular on the liquid core." Ongoing measurements of the rotation of Mars using the RISE experiment on InSight - the robotic lander studying the Red Planet's deep interior which launched in 2018 - is already proving exciting, and could lead to many breakthroughs.

"By comparing the measured nutation with the external forcing, the core radius can be determined, and constraints on the chemical composition of the core be deduced," Dehant adds. "Unlike the Chandler wobble, a resonant amplification can only occur if Mars has a liquid core. By measuring the Chandler wobble and the nutations, complementary knowledge about the interior structure of Mars can be obtained." Scientists are sure to be shaking with excitement at what could be unearthed.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.



© NASA/JPL-Caltech

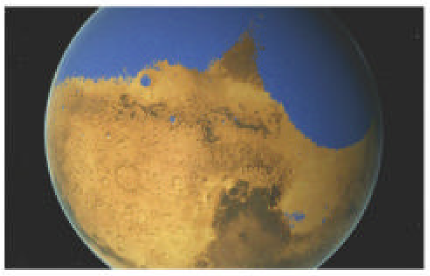
Left: Polar motion has not been detected for any other Solar System body other than Mars and Earth

THE THEORIES

What could be keeping the Chandler wobble going on Mars?

1 Past evidence of surface water

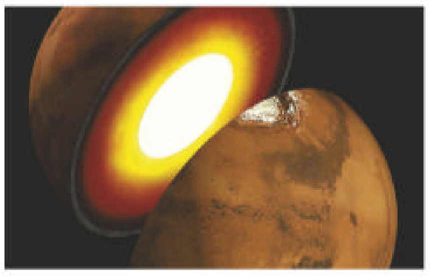
On Earth, the Chandler wobble is excited, in part, by pressure at the bottom of the ocean, but Mars does not have surface water today. It lost flowing liquid billions of years ago, but it was once awash with water in the form of lakes and oceans. Could that have aided the wobbly rotation? As it stands, it would require much further study.



© NASA

2 Internal issues

Researchers have considered whether the excitations are produced by core-mantle interactions or marsquakes. Neither can be excluded at this stage, but the scientists believe them to be unlikely. Past research has already suggested that marsquakes are too small to excite polar motion to an observable level.



© NASA

3 Seasonal atmospheric pressure changes

Mars has two ice caps - north and south - that are made of frozen water. Over each pole's respective winter, this is accompanied by a layer of frozen carbon dioxide, which melts and reforms seasonally. The atmospheric pressure changes related to the seasonal mass exchange between the two caps are thought to be the principal mechanism behind the ongoing Chandler wobble.

© NASA

© Getty

SOLAR SYSTEM

Why do all the planets orbit the Sun in the same direction?

The reason is what's known as 'conservation of angular momentum'. Think of a figure skater doing a spin and pulling in their arms. The Solar System formed from the collapse of a huge cloud of gas and dust. As it collapsed, any net rotation would cause most of the cloud to settle into a flattened rotating disc. Collisions between dust and friction within the gas would drag material into the same motions as the majority of the gas and dust. Collisions between dust grains would build up to larger bodies, planetesimals, which would ultimately collide to form the planets. The general revolution of the disc would transfer to the rotating planets and to the Sun itself.

Most of the angular momentum of the Solar System is in the outer planets, both in rotation and orbital motion. The Sun itself rotates very slowly, about once a month, while Jupiter and Saturn rotate once every ten hours. Among the planets, only Venus and Uranus fail to share this common rotation. Venus rotates backwards - or it's tipped upside down - while Uranus is tipped so its axis is close to the plane of its orbit. We believe these are due to violent collisions when the Solar System was still very young.

Dr George Spagna, chair of the physics department at Randolph-Macon College

Above: All eight planets of the Solar System follow an anti-clockwise path round the Sun

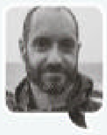
SPACE EXPLORATION

How was the landing site for ExoMars chosen?

It was a combination of things. Oxia Planum is interesting because it's really old, and it's in the right place, because the mission has certain constraints. For example, it can't land anywhere that has too high an elevation because it needs a certain thickness of atmosphere for the parachutes to work.

You can't land at the top of a mountain because you'll be going too fast when you hit the surface. Oxia Planum has quite a low elevation, and it's in the right latitude range. The ExoMars rover is going to look for life, so the landing site's got a lot of what we call 'clay minerals', which are hypothesised to be good preservers of biomarkers, and they often form due to the presence of liquid water underground. That's both the habitable environment and good preservation of anything that we might be able to detect.

On top of that, just to make it even better, it's also got sort of a big, ancient river channel coming into one end of the site. At the end of it it's got a fan-shaped deposit about ten kilometres [six miles] across. And that has got people thinking that it was brought there by flowing water. Scientifically it's a really interesting place to go, but also it's safe, it's relatively flat, it's relatively low elevation and the winds aren't too strong. It's a place where we feel that the mission will have the best chance of success.



Dr Matt Balme, a senior lecturer at the Open University who specialises in planetary science

© ESA

Right: The Rosalind Franklin rover of the ExoMars mission is due for launch in September 2022

Did you know?

Mariner 9 became the first artificial satellite of Mars when it entered orbit on 14 November 1971.

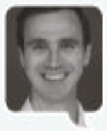
© Kevin McGivern

Right: Space debris could cause problems on spacewalks if junk continues to accumulate

SPACE EXPLORATION

How are we going to clean up all the space debris?

Planning is already underway to start testing the technologies needed to remove large pieces of space debris. For example, the ClearSpace-1 mission slated to launch in 2025 is aiming to remove the upper stage of a rocket that has been orbiting since 2013. This is just one piece of debris among the tens of thousands that we actively track, which are a tiny fraction of the millions that pose a danger to our continued use of space. In order to ensure our long-term access to space, we have to start with answering some of the more fundamental questions related to cleaning up space debris. How can we better track space debris objects using our existing radars and telescopes? How can we make sure this data is accessible to everyone that needs it? How can we avoid collisions? All these issues must be tackled in concert with the development of debris-removal missions if we are serious as a species about maintaining our access to our orbital environment.



Stuart Grey, University of Strathclyde

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ASTROPHYSICS

Why do we say that nothing has weight in space?

When 'floating' in space, your weight is the sum of the gravitational forces from all objects surrounding you, which can be negligible when sufficiently far away from heavy celestial objects. What most people think of when they speak of 'weight' is the number they see on a scale - however, that is in fact their 'mass'. In contrast, weight is a measure of the force (in Newton units) of gravity on an object. Your weight in space depends on both the mass of the celestial objects exerting a gravitational pull and your distance from their centre. You could easily bounce higher on the Moon than on Earth because your weight would be lower on the surface of the comparatively less massive Moon. The further away you are from massive celestial objects - be it the Moon, planets like our Earth, stars like our Sun or black holes - the less you feel their gravity.

Dr Caroline Foster, ASTRO3D research fellow at the University of Sydney

Above: The ISS experiences many sunrises and sunsets as it orbits Earth

Left: NASA astronaut Karen Nyberg appears to be 'floating' alongside fruit aboard the ISS

SPACE EXPLORATION

How do you tell the time on the ISS?

The International Space Station (ISS) flies around the Earth at 28,160 kilometres (17,500 miles) per hour, completing each orbit in 90 minutes, which means the crew see 16 stunningly beautiful sunrises and sunsets every 24 hours. This means that the crew can't use the passing of the Sun to help mark out days, and instead had to pick a time zone. Right now, in February, it is the same time on the ISS as it is in the UK, Iceland and Ghana. That's because the space agencies around the world that built the station decided that it should use Coordinated Universal Time, or UTC. This is a convenient compromise between the times in Houston and Moscow, the two cities where the two main control centres for the ISS are located, and means that the flight controllers in each country have their days overlapping with half of the crew's day. Once a new crew arrives at the station, they can simply set their wristwatches to the new time zone, just like you might when travelling, and then settle into their new home up in the sky.

Libby Jackson, human exploration program manager at the UK Space Agency

Did you know?

The Lunar Reconnaissance Orbiter sent a clear map of the Moon to Earth in 2011.

SOLAR SYSTEM

How do you map a planet or moon?

Mapping a planet or moon really comes down to finding and interpreting patterns in orbital images. Things like the colour and texture of the surface can actually tell us a lot about what's down there, whether it's rocks, dirt or even ice. These patterns can give us hints about the types of rocks on the surface, how they formed and how old they are. If a rock has layers, it might have once formed in a body of water, like a lake. If there are a lot of craters nearby, it's likely very old. We can even look at the different types of light coming from the surface to get a good idea of what the rocks are made of using spectroscopy. As mappers, we try to use all of this information to split up the surface into regions with common characteristics and look at how they are distributed and relate to each other across the map. Putting all this together tells us a story about the history of a planet or moon.

Dr Vivian Z. Sun, planetary scientist at NASA's Jet Propulsion Laboratory

© Getty

Right: Observations over time help form a map of a planet

> "LIKE A COOKING POT THAT'S BEEN TAKEN OFF THE HOB, ALL IT CAN DO IS COOL"
>
> MATT CAPLAN

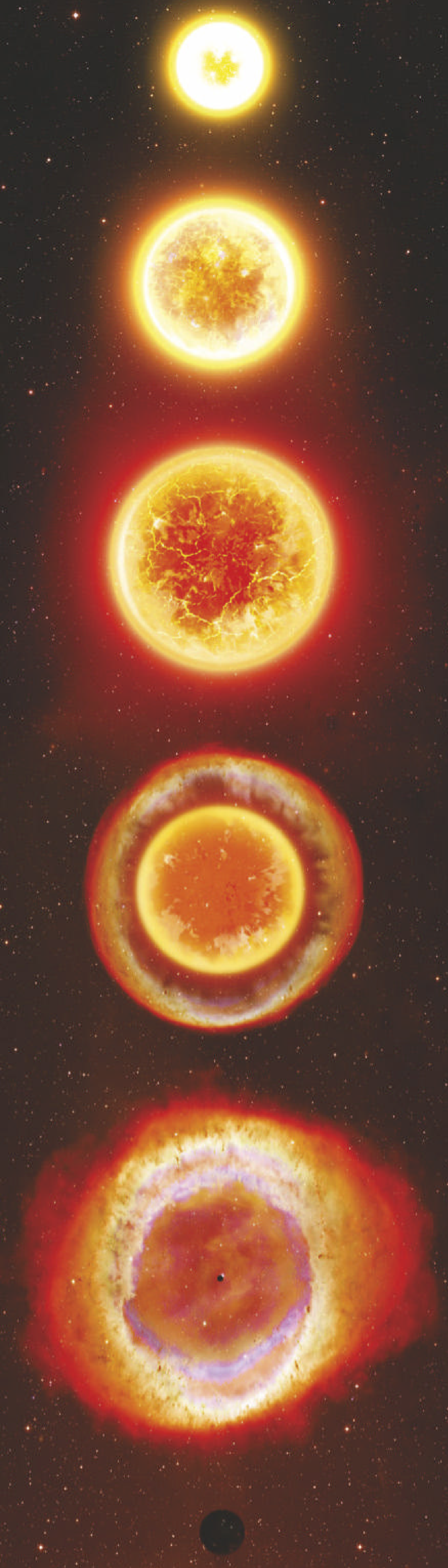
ASTROPHYSICS

What makes astronomers think black dwarf stars exist?

When a star like our Sun exhausts the fuel in its centre, the core will contract, reaching extreme temperatures of millions of degrees. The star swells into a red giant, but not for long. The heat of the core is so great that it overcomes gravity, lifting off the outer layers of the star in massive stellar winds and exposing the glowing ember of the core: a white dwarf.

The exposed core of a star is quite hot, but since they've run out of fuel they can't stay that way forever. Like a cooking pot that's been taken off the hob, all it can do is cool. White dwarfs fade over billions of years as the heat leaks out, carried away by starlight, first turning a dim red colour until eventually vanishing from view entirely. Now dark and frozen, it is said to be a 'black dwarf'. But the time it takes to cool this cold is far longer than the universe has existed - even the oldest, coldest white dwarfs in our galaxy are 5,500 degrees Celsius (10,000 degrees Fahrenheit) and will take billions more years to turn black. While we don't have any black dwarfs yet, their time will inevitably come.

Dr Matt Caplan, professor of physics at Illinois State University



The existence of these dark, dead stars may be proven in the future as stellar evolution is researched further

© Tobias Roetsch

© Getty

What's in the sky?

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© NASA

27 MAR
Dwarf planet Makemake reaches opposition at magnitude +17.1 in Coma Berenices

29 MAR
Venus is at its brightest, dazzling at magnitude -3.9 in the evening sky

5 APR
Asteroid 9 Metis reaches opposition, glowing at magnitude +9.5 in Virgo

6 APR
Conjunction between the Moon and Saturn in Capricornus

6 APR
The Moon and Saturn make a close approach, within 3°51' of each other in Capricornus

7 APR
The Moon and Jupiter make a close approach, within 4°10' of each other in Capricornus

15 APR
The Whirlpool Galaxy (Messier 51) is well placed in Canes Venatici at +8.4

17 APR
The Moon will pass in front of Mars, creating a lunar occultation

22 APR
The Lyrids reach their peak of around 18 meteors per hour

© Hubble Image: NASA, ESA

23 APR
The Pinwheel Galaxy (Messier 101) is well placed in Ursa Major at magnitude +7.9

Red light friendly
In order to preserve your night vision, you should read our observing guide under red light

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

2 APR

The Sombrero Galaxy (Messier 104) is well placed for observation at +8.0 in Virgo

5 APR

Messier 94 is well placed for observation, glowing at +9.0 in Canes Venatici

Source: Wikipedia Commons © R Jay Gabany (Blackbird Obs.)

© NASA

7 APR

Conjunction between the Moon and Jupiter in Capricornus

17 APR

Conjunction between the Moon and Mars in Taurus

18 APR

Globular cluster Messier 3 is well placed for observation in Canes Venatici

18 APR

Dwarf planet Haumea is well placed for observation in Boötes at magnitude +17.3

23 APR

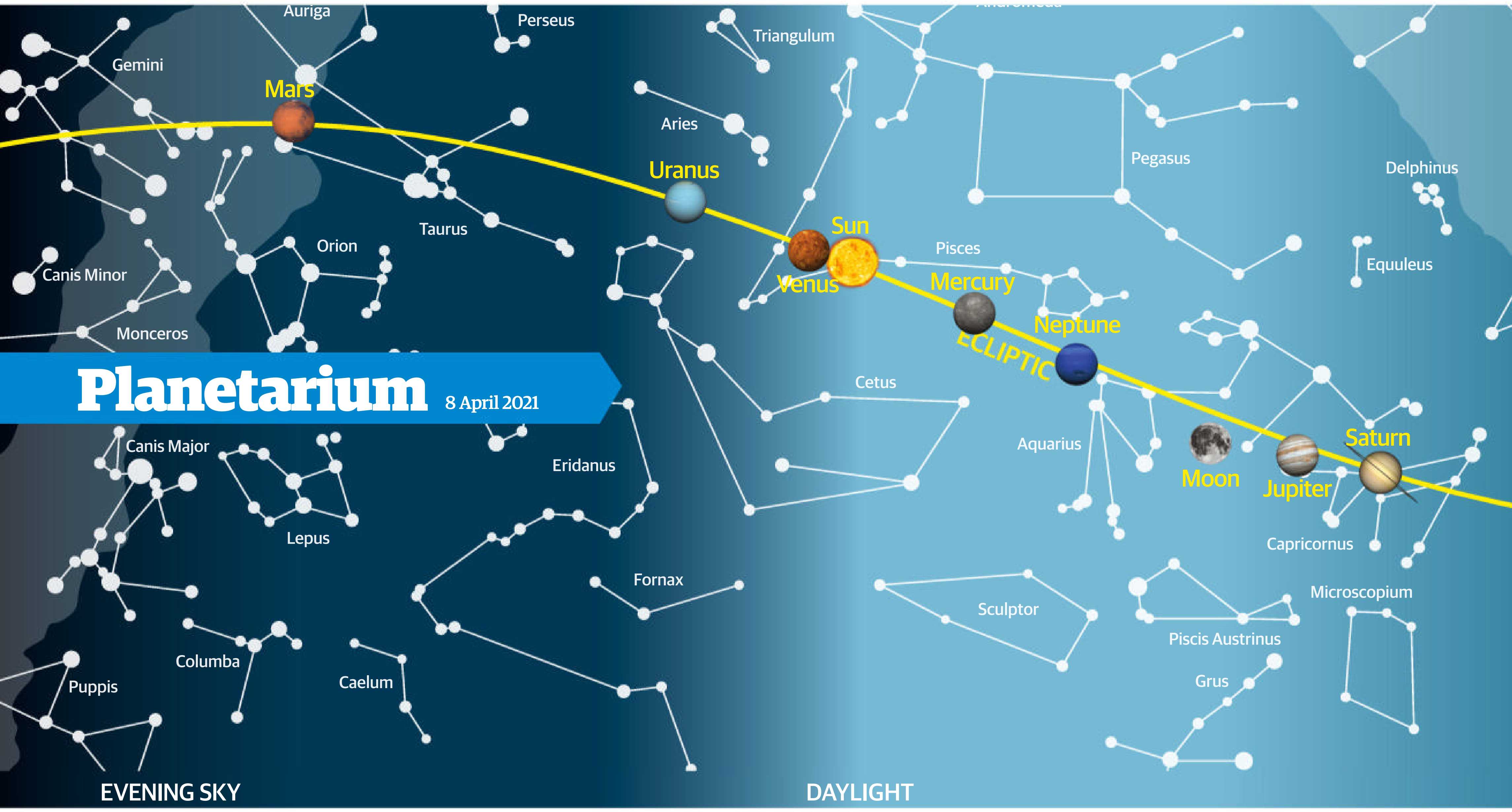
C/2020 R4 (ATLAS) makes a close approach to Earth, with a predicted magnitude of +7.3

© NASA/ESA

Naked eye
Binoculars
Small telescop
Medium telesc
Large telescop

Planetarium

8 April 2021



Moon calendar

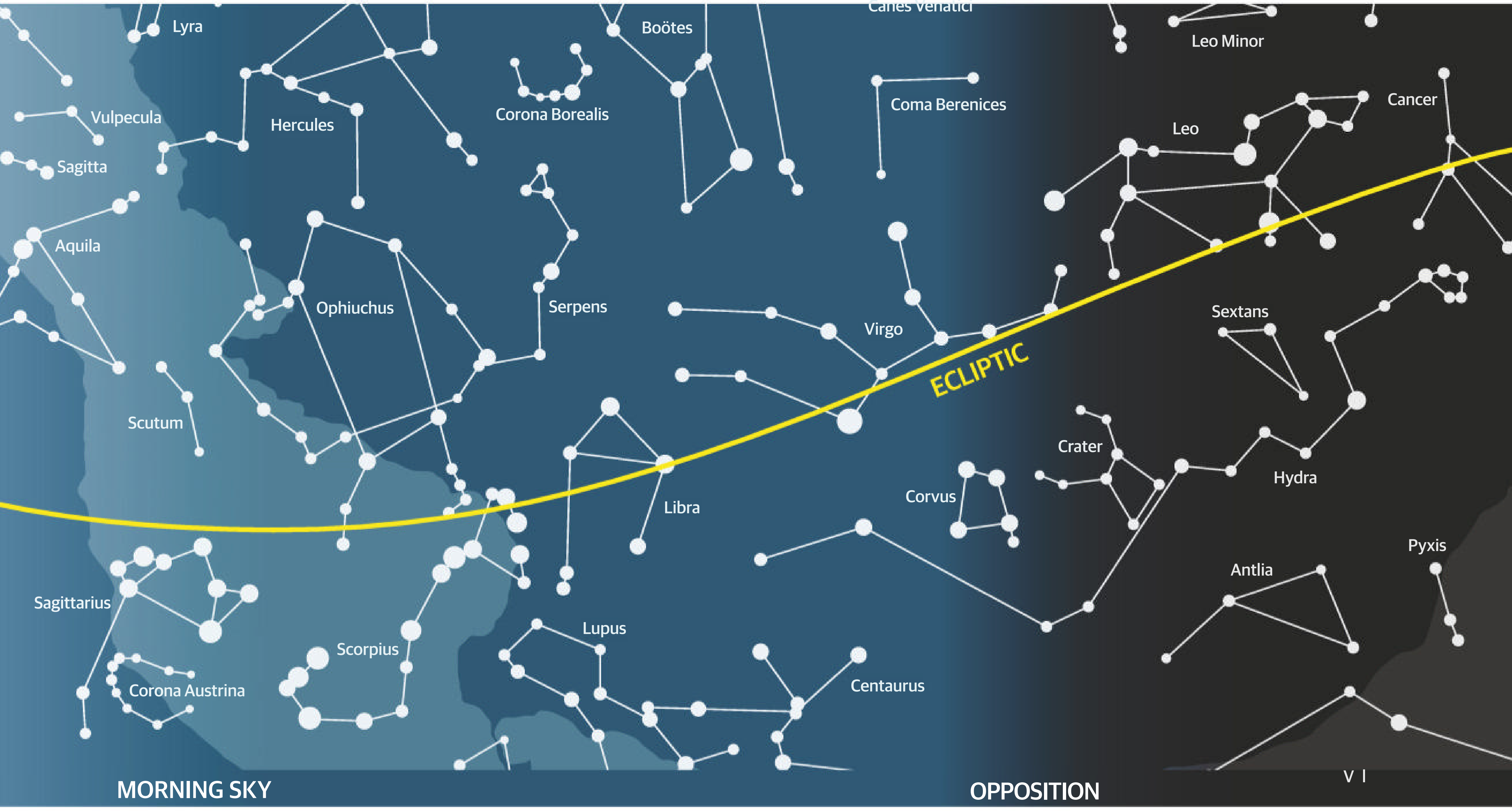
* The Moon does not pass the meridian on 28 March

Date	Phase	Illumination	Moonrise	Moonset
25 MAR		88.9%	13:53	05:01
26 MAR		95.1%*	15:15	05:26
27 MAR		98.9%	16:40	05:47
28 MAR	FM	--:--*%	19:06	07:06
29 MAR		99.8%	20:34	07:24
30 MAR		97.5%	22:02	07:43
31 MAR		92.3%	23:32	08:04
1 APR		84.4%	--:--	08:31
2 APR		74.5%	00:58	09:04
3 APR		63.5%	02:17	09:49
4 APR	LQ	51.9%	03:24	10:46
5 APR		40.6%	04:16	11:54
6 APR		30.1%	04:54	13:08
7 APR		20.8%	05:22	14:23
8 APR		13.0%	05:43	15:37
9 APR		6.9%	06:01	16:50
10 APR		2.7%	06:16	18:00
11 APR		0.5%	06:29	19:09
12 APR	NM	0.3%	06:43	20:18
13 APR		1.9%	06:58	21:27
14 APR		5.5%	07:15	22:36
15 APR		10.7%	07:35	23:45
16 APR		17.4%	08:00	--:--
17 APR		25.5%	08:33	00:51
18 APR		34.7%	09:15	01:52
19 APR		44.6%	10:10	02:44
20 APR	FQ	55.1%	11:14	03:27
21 APR		65.7%	12:28	04:01
22 APR		75.9%	13:47	04:28

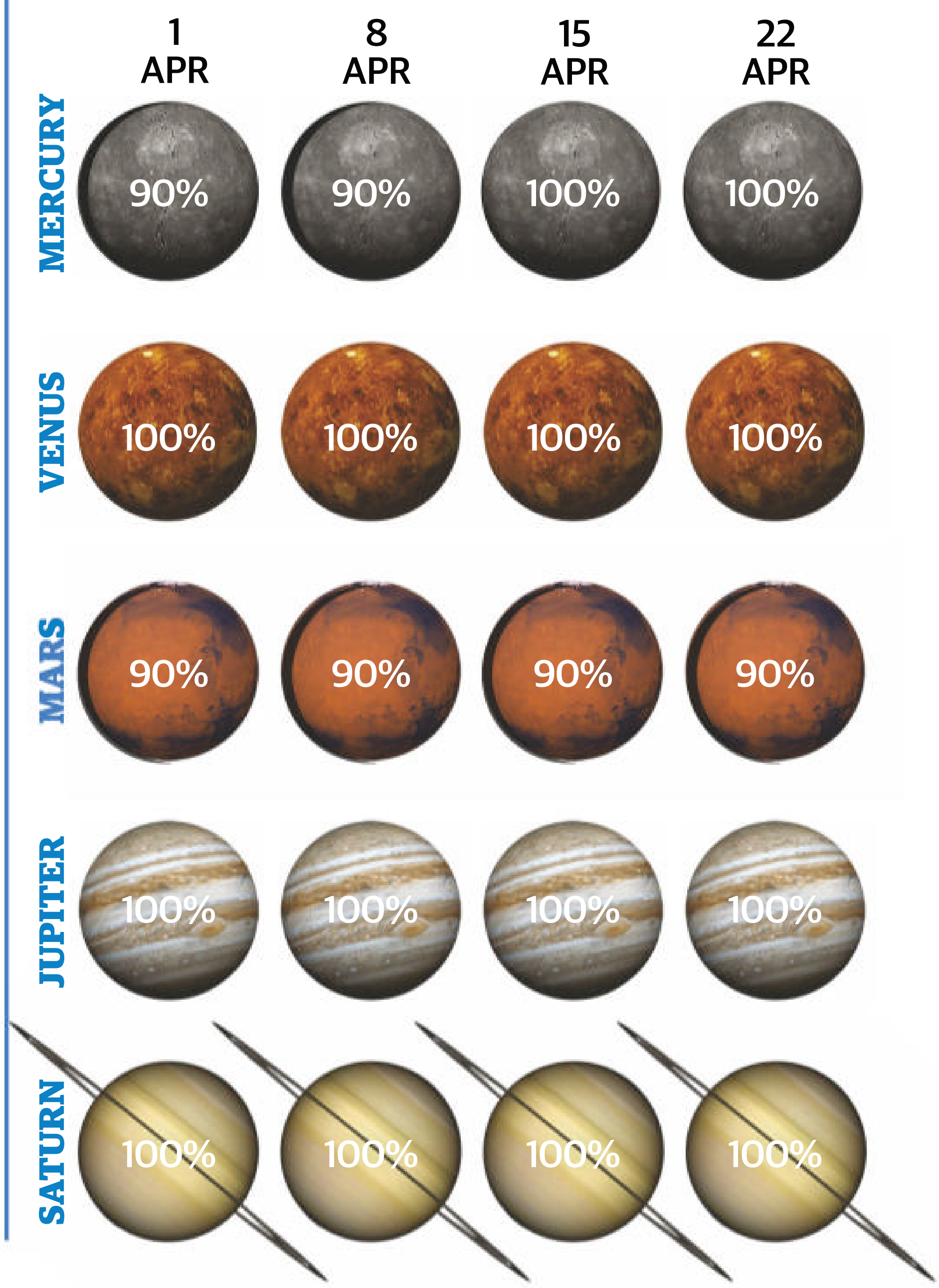
% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage



	1 APR	8 APR	15 APR	22 APR
MERCURY	90%	90%	100%	100%
VENUS	100%	100%	100%	100%
MARS	90%	90%	90%	90%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

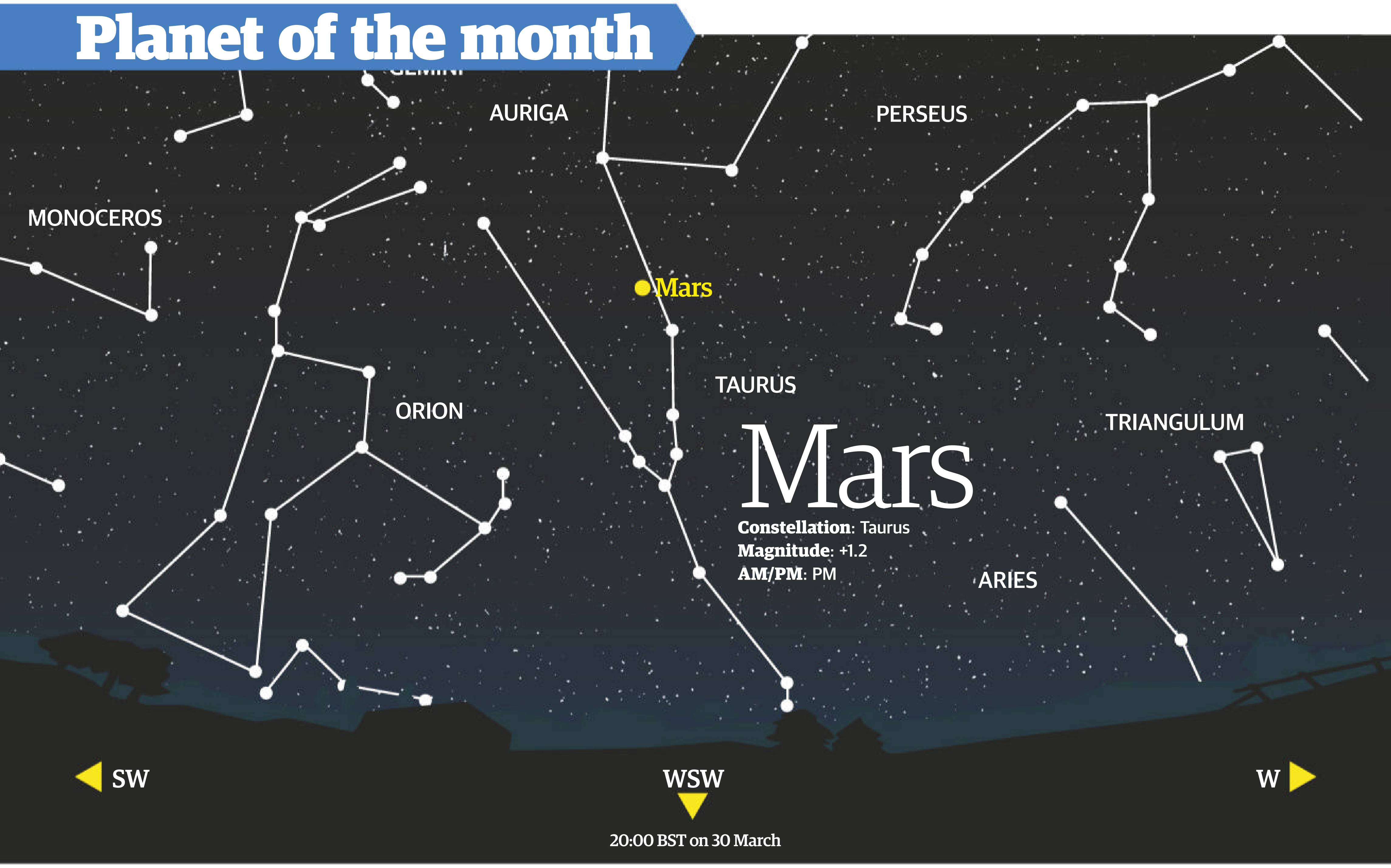
All rise and set times are given in GMT/BST

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	25 MAR	23h 00m 06s	-08° 52' 34"	Aquarius	-0.2	05:40	16:13
	1 APR	23h 42m 25s	-04° 26' 15"	Aquarius	-0.5	06:30	17:51
	8 APR	00h 27m 56s	+00° 52' 49"	Cetus	-0.9	06:20	18:37
	15 APR	01h 17m 29s	+06° 53' 54"	Pisces	-1.7	06:10	19:31
	22 APR	02h 11m 37s	+13° 10' 42"	Aries	-2.0	06:01	20:33
VENUS	25 MAR	00h 16m 41s	+00° 18' 57"	Pisces	-3.9	06:07	18:18
	1 APR	00h 48m 31s	+03° 50' 12"	Pisces	-3.9	06:53	19:41
	8 APR	01h 20m 32s	+07° 17' 41"	Pisces	-3.9	06:38	20:04
	15 APR	01h 52m 59s	+10° 37' 12"	Aries	-3.9	06:25	20:27
	22 APR	02h 26m 01s	+13° 44' 31"	Aries	-3.9	06:12	20:51
MARS	25 MAR	04h 41m 03s	+23° 41' 28"	Taurus	+1.2	08:10	01:06
	1 APR	04h 59m 11s	+24° 11' 27"	Taurus	+1.3	08:57	02:01
	8 APR	05h 17m 33s	+24° 33' 39"	Taurus	+1.4	08:44	01:54
	15 APR	05h 36m 05s	+24° 47' 47"	Taurus	+1.4	08:33	01:47
	22 APR	05h 54m 44s	+24° 53' 39"	Taurus	+1.5	08:24	01:39
JUPITER	25 MAR	21h 36m 30s	-14° 55' 16"	Capricornus	-2.1	04:51	14:15
	1 APR	21h 42m 01s	-14° 29' 00"	Capricornus	-2.1	05:26	14:55
	8 APR	21h 47m 14s	-14° 03' 42"	Capricornus	-2.1	05:01	14:35
	15 APR	21h 52m 08s	-13° 39' 39"	Capricornus	-2.1	04:36	14:15
	22 APR	21h 56m 42s	-13° 17' 07"	Capricornus	-2.2	04:11	13:54
SATURN	25 MAR	20h 52m 25s	-18° 05' 07"	Capricornus	+0.8	04:26	13:11
	1 APR	20h 54m 45s	-17° 56' 30"	Capricornus	+0.8	05:00	13:47
	8 APR	20h 56m 51s	-17° 48' 47"	Capricornus	+0.8	04:34	13:22
	15 APR	20h 58m 41s	-17° 42' 05"	Capricornus	+0.7	04:07	12:57
	22 APR	21h 00m 14s	-17° 36' 31"	Capricornus	+0.7	03:41	12:32

This month's planets

The Red Planet remains an easy target, while Uranus presents itself as an interesting sight

Planet of the month



Mars

Constellation: Taurus
Magnitude: +1.2
AM/PM: PM

20:00 BST on 30 March

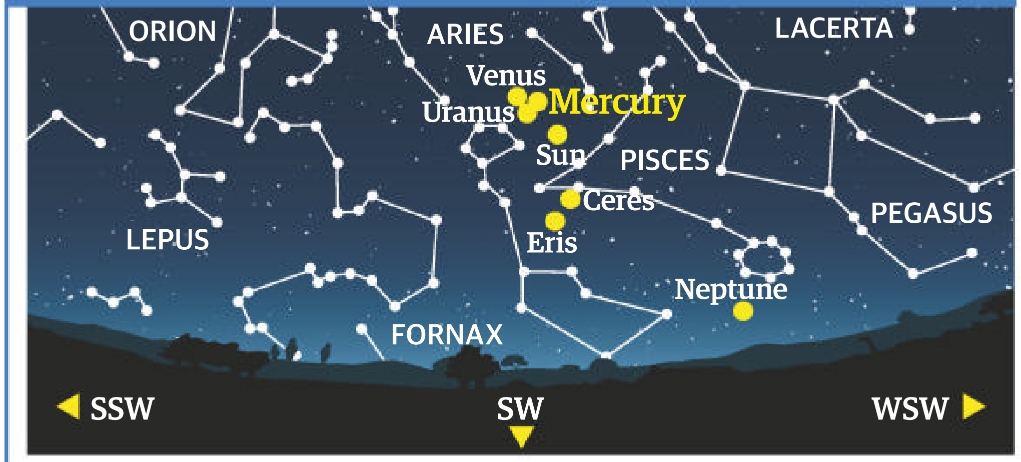
Comparing how Mars looks now to how it looked last autumn, when it was at opposition and much closer to the Earth, is like comparing a candle to a car headlight, but the Red Planet is still an easy naked-eye object, and it's in a very interesting and busy part of the night sky, too. As March draws to a close, Mars is shining at magnitude +1.2, making it still as bright as the star Pollux, but strikingly fainter than the sky's brightest stars, which it was outshining last October.

At the start of our observing period Mars will become visible to the naked eye soon after sunset as an orange-hued star just to the upper right of the V-shaped Hyades star cluster, which represents the sharp horns of Taurus (the Bull), and not far from the red star Aldebaran. The two will be shining at roughly the same brightness, making a very attractive pairing in the sky. Mars will remain visible all through the evening before setting at around 01:00.

As the days pass Mars will move towards Taurus' boundary with Gemini, drifting slowly away from the Hyades and Aldebaran, and fading too. By mid-April Mars will have left Aldebaran and the Hyades far behind, and will have almost reached the border with Gemini. Hope for clear skies around that time, because Mars will be joined in the evening twilight by a lovely young crescent Moon. On the evening of 16 April Mars will lie eight degrees to the Moon's upper left. By the following evening the two will have swapped positions, so the Moon will lie to Mars' upper left instead. On both of these evenings the pair will look beautiful through binoculars, and the camera on your phone should photograph them easily.

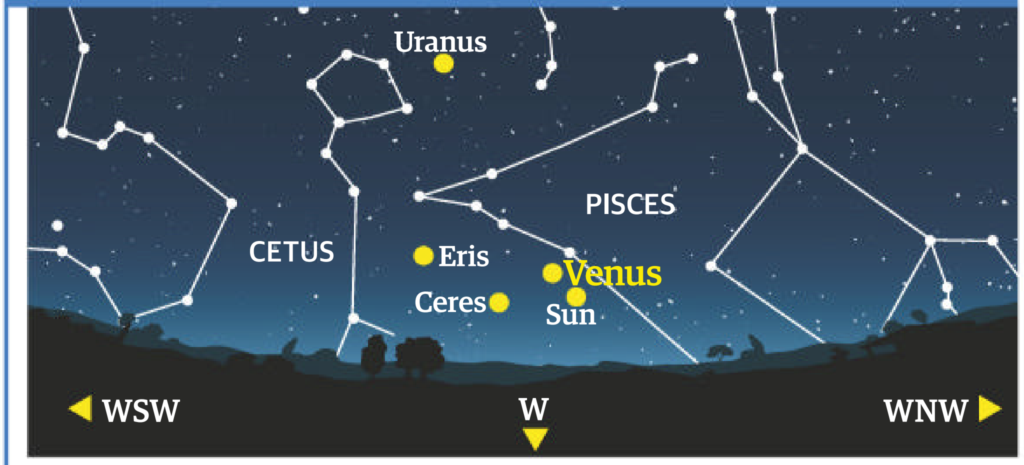
By the end of April Mars won't be setting until around 02:00, but it will have faded to magnitude +1.5, making it only slightly brighter than the stars of Orion's Belt, but it will still be an attractive naked-eye sight. If your naked-eye views of Mars are disappointing this month, you'll be able to enjoy rather more dramatic views of it through the many cameras being carried by the Perseverance rover, which will be posted on NASA websites for everyone to enjoy.

Mercury 15:00 BST on 24 April



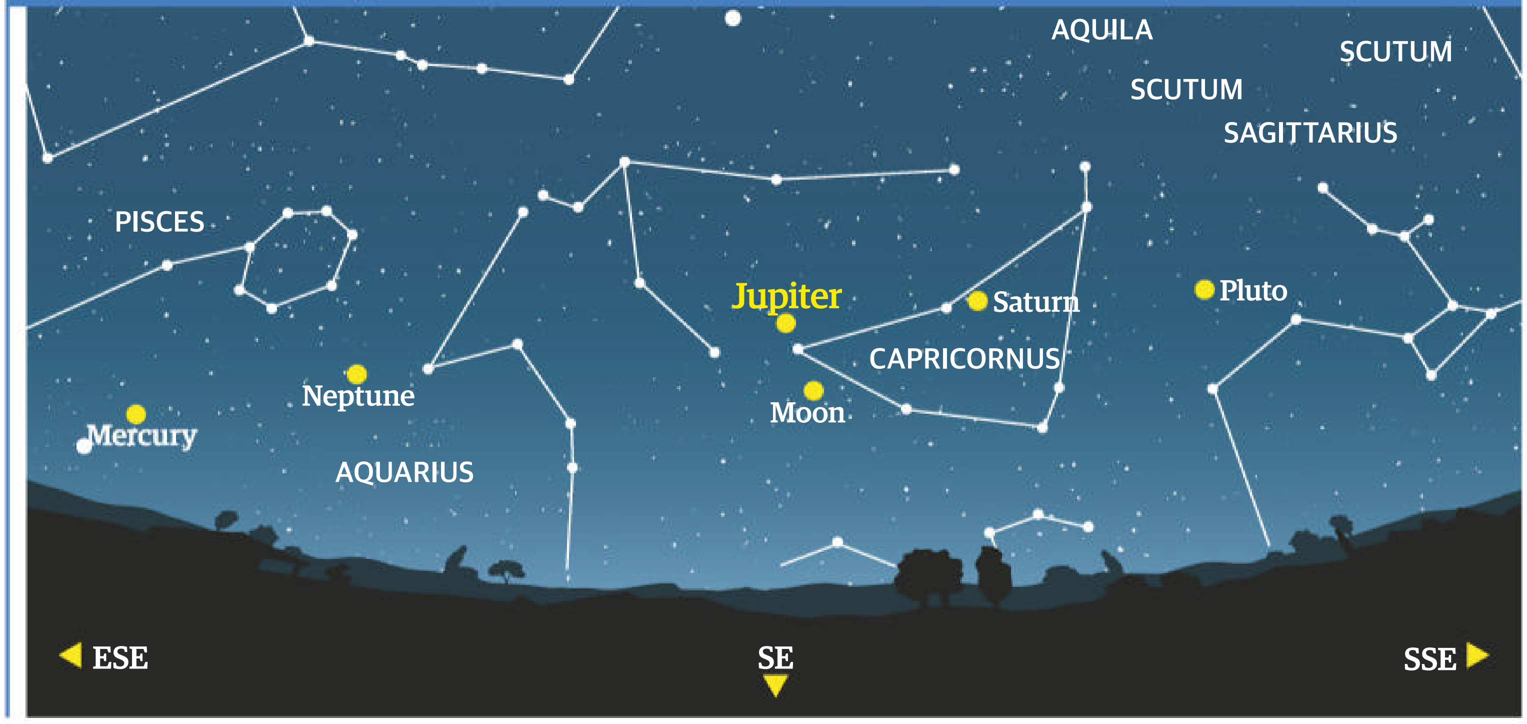
Constellation: Aries
Magnitude: -0.3
AM/PM: PM
At the start of our observing period Mercury will be rising at the same time as the Sun, so it won't be observable. By the end of April it will have moved up into the evening twilight and might just be glimpsed through binoculars very low in the southwest after sunset as a faint, copper-hued star.

Venus 19:00 BST on 3 April



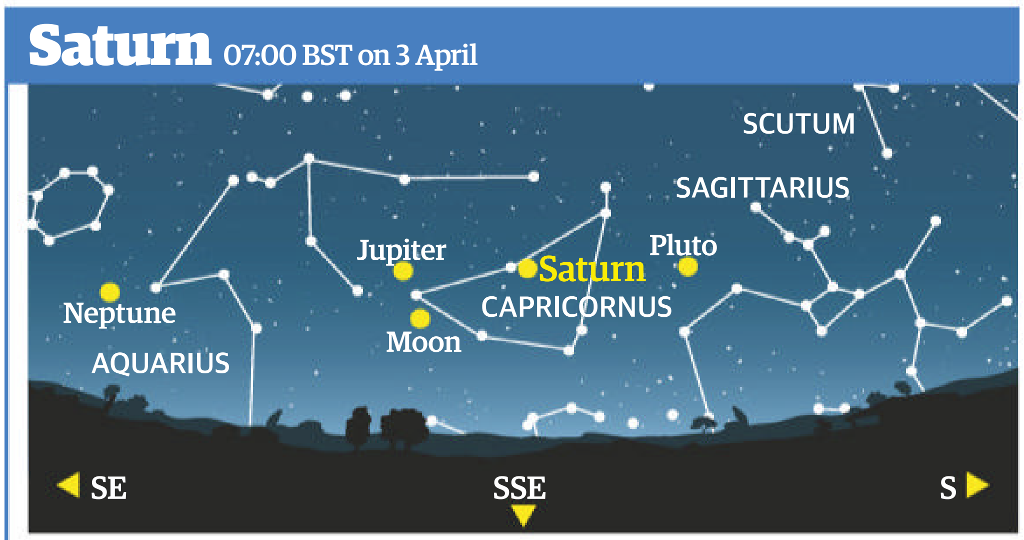
Constellation: Pisces
Magnitude: -3.9
AM/PM: PM
At the start of our observing period Venus will be too close to the Sun to be visible, setting very shortly after our star. As March moves into April, Venus will slowly pull away from the Sun and begin to climb higher in the sky, but will still be very challenging to see in the bright evening twilight.

Jupiter 07:00 BST on 3 April



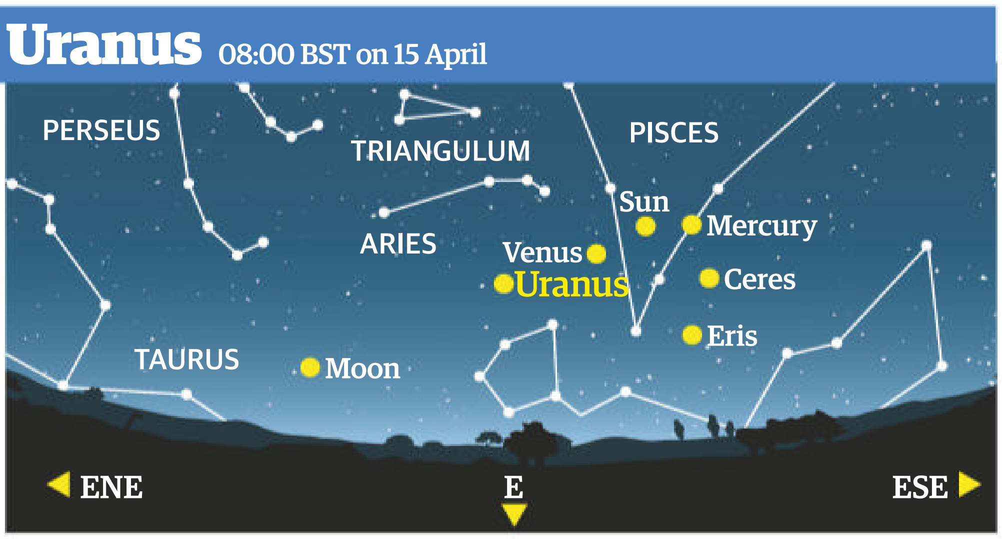
Constellation: Capricornus
Magnitude: -2.0
AM/PM: AM
After dominating the evening sky last summer, Jupiter is a 'morning star' at the moment, shining low before sunrise. As it rises less than an hour before the Sun, the huge gas giant won't be obvious to the naked eye, and at best will look like a reasonably bright star low in the sky as dawn approaches. By the end of our observing period Jupiter will be rising a little earlier, but not much, so will be hardly any easier to see. If your sky is clear before dawn on the morning of 7 April, you might catch a glimpse of a crescent Moon shining very close to Jupiter, to its lower right.

Saturn 07:00 BST on 3 April



Constellation: Capricornus
Magnitude: +0.8
AM/PM: AM
Saturn is visible very low in the sky for a short time before sunrise, shining to the upper right of brighter and more obvious Jupiter. However, with the predawn sky being so bright, Saturn will be much harder to see than its magnitude of +0.8 suggests, and you might need a pair of binoculars to find it.

Uranus 08:00 BST on 15 April



Constellation: Aries
Magnitude: +5.9
AM/PM: AM
Uranus, the penultimate planet, is a morning object this month but you'll only have a few fleeting hours to see it between sunrise. When the sky begins to brighten, Uranus will already be dropping down towards the east. Due to its faint magnitude, you'll need binoculars to pick it out of the sky.

Moon tour

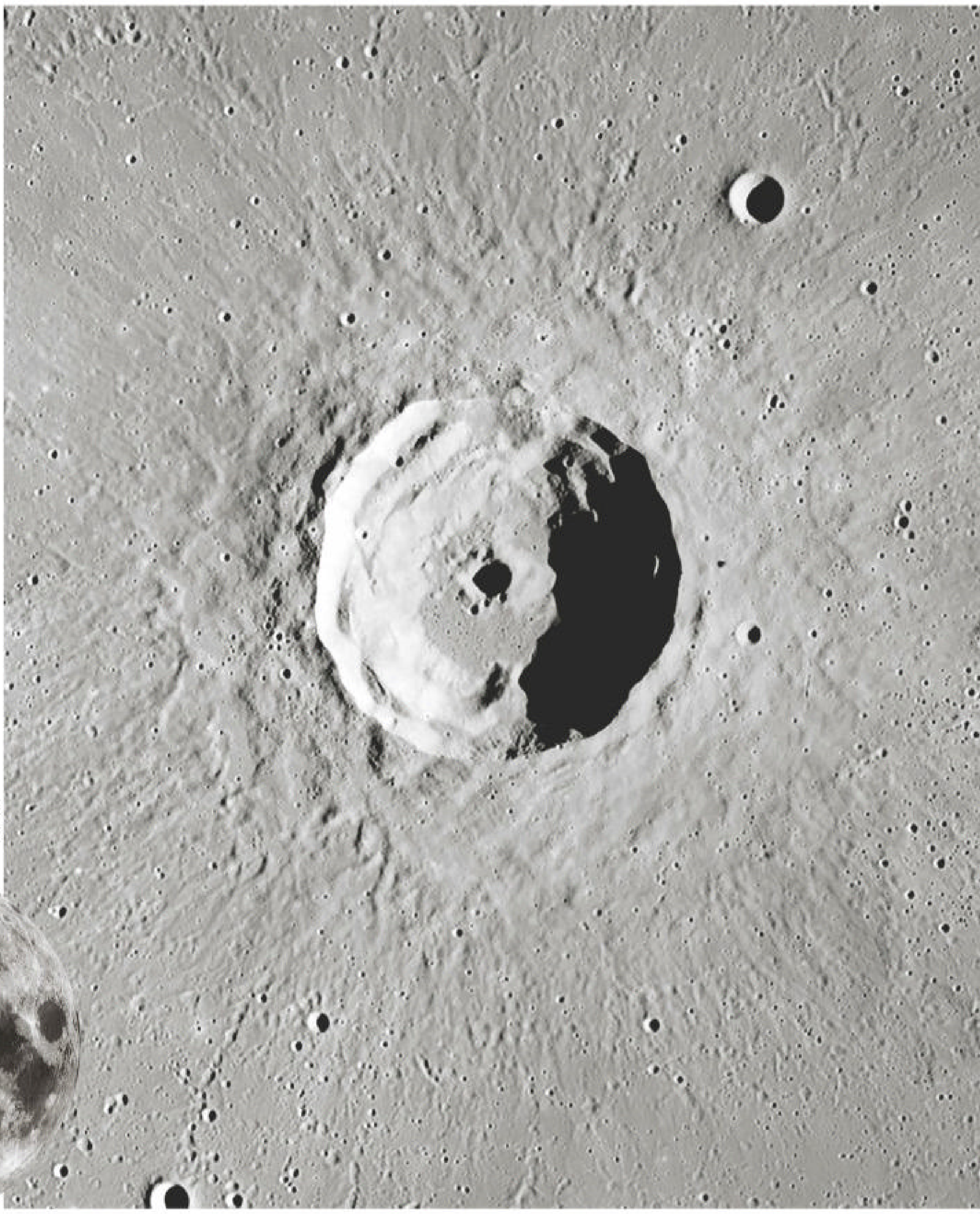
Timocharis

Go on a sightseeing tour of a little crater with a very violent past

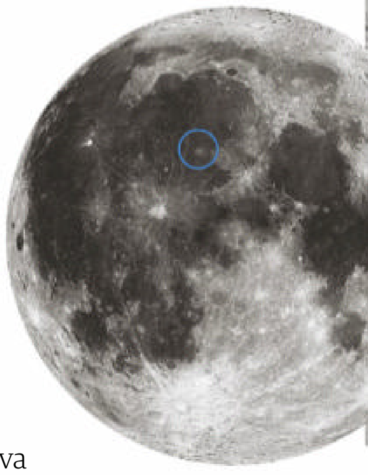
Up near the top of the lunar disc, nestled in the curve of the rugged Montes Apenninus, is a small crater called Timocharis. It really doesn't look like anything special; the Moon is spattered with countless tens of thousands of craters just like it, each one proof that our satellite has been absolutely pummelled and pulverised in its distant past by asteroids and comets that were left circling the Sun after it was born 4.6 billion years ago. Some of these impact craters are enormous, and lunar observers gaze at them again and again, ignoring the smaller holes surrounding them. But some of these small craters have fascinating stories behind them too, and deserve more than just a fleeting glance, such as Timocharis.

Top tip!

Timocharis will be most obvious when it is close to the terminator, when the Sun's rays illuminate it from a low angle.



© NASA



The crater was named in 1651 by the skilled lunar cartographer and observer Giovanni Battista Riccioli to honour the Greek astronomer and philosopher Timocharis, who not only worked in the famous Great Library of Alexandria, but very accurately measured lunar star occultations and observed a planetary occultation by Venus.

Timocharis lies in the Sea of Showers, Mare Imbrium, a vast, dark plain of ancient frozen lava which represents one of the eyes of the 'Man in the Moon'. It is just 34 kilometres (21 miles) across and three kilometres (1.86 miles) deep, and forms a tight triangle with - but is dwarfed by - its near neighbours, enormous 96-kilometre (59.6-mile) Copernicus to the southwest and 59-kilometre (36.6-mile) Eratosthene directly to its south.

In lunar terms Timocharis is a relatively young feature, as is proven by the fact that it is not surrounded by any major bright beams or pale splashes of debris. At full Moon you can see some subtle rays spreading away from Timocharis, but they are pale imitations of those which surround its bigger, older neighbours.

If you take the time to hunt it down with your telescope, a high-power eyepiece reveals Timocharis to be a surprisingly complicated feature. It is roughly polygonal in shape, with sharp, rugged outer walls, the inner slopes of which are broken up into multiple ledges and terraces. In some places these have slumped down towards the crater's floor. When sunlight is striking Timocharis from a steep angle - for example when it is near the terminator, it can look like a stony bullseye in the eyepiece.

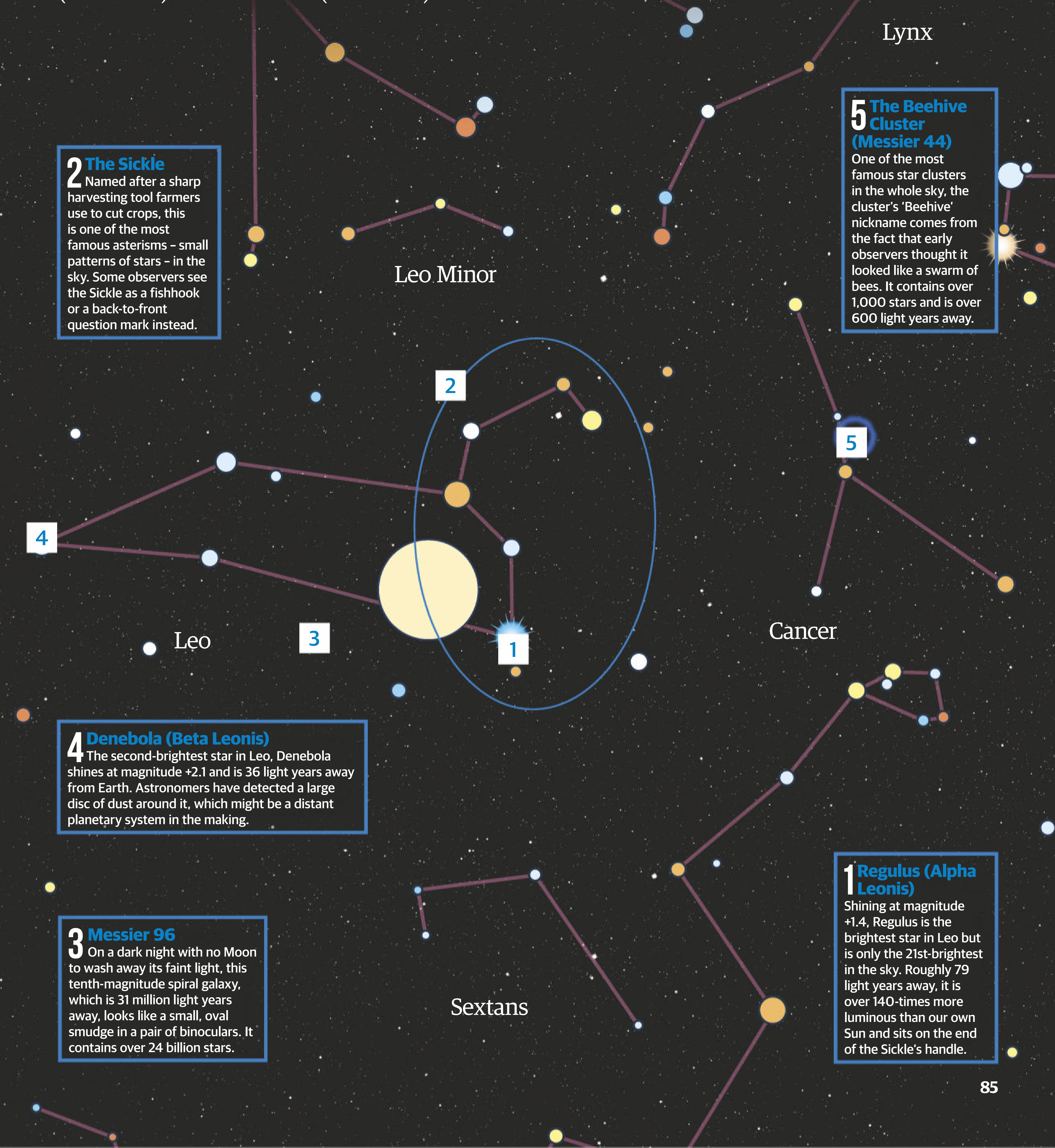
On still evenings of really good seeing, a high-power eyepiece will show Timocharis has a central mountain peak - or rather it used to. Once, long ago, a towering mountain rose above Timocharis' floor, but now there is a small, deep crater there. Some time after Timocharis was formed, an asteroid came barrelling in from deep space and slammed into the mountain at its centre, obliterating it and scattering its shattered pieces across the crater floor, leaving behind a hole which now stares out from the heart of Timocharis like an empty eye socket. Many of the countless tiny craters you'll see spattered across Timocharis' floor and slopes were probably formed by that impact.

At the start of our observing period on 25 March, the Moon will be in its waning gibbous phase, just a couple of days away from full, so Timocharis will be in full sunlight. At this time, seen through a telescope the crater will be a pale-grey ring with a dark centre. It won't be until 1 April, when the Moon is approaching its first quarter phase, that the crater will begin to show any kind of detail. With the setting Sun's rays coming in at a lower angle, the crater's walls and internal features will cast shadows that will make them stand out more clearly.

By 4 April the crater will stand out starkly in an eyepiece, looking like a round pit with a jumbled floor, and subtle details on its surrounding slopes will be more obvious too. On the evening of 5 April the terminator will be almost upon the crater, and this is when it will look most dramatic through a telescope - even a small one will show it standing out very clearly. By the next evening Timocharis will have been enveloped in darkness, and it will remain in darkness until the evening of 20 April, when the Sun rises above its local horizon and sunlight splashes over its walls and down onto its jumbled floor once more.

Naked eye & binocular targets

Early spring is a great time to explore Leo (the Lion) and Cancer (the Crab)



1 Regulus (Alpha Leonis)

Shining at magnitude +1.4, Regulus is the brightest star in Leo but is only the 21st-brightest in the sky. Roughly 79 light years away, it is over 140-times more luminous than our own Sun and sits on the end of the Sickle's handle.

2 The Sickle

Named after a sharp harvesting tool farmers use to cut crops, this is one of the most famous asterisms – small patterns of stars – in the sky. Some observers see the Sickle as a fishhook or a back-to-front question mark instead.

3 Messier 96

On a dark night with no Moon to wash away its faint light, this tenth-magnitude spiral galaxy, which is 31 million light years away, looks like a small, oval smudge in a pair of binoculars. It contains over 24 billion stars.

4 Denebola (Beta Leonis)

The second-brightest star in Leo, Denebola shines at magnitude +2.1 and is 36 light years away from Earth. Astronomers have detected a large disc of dust around it, which might be a distant planetary system in the making.

5 The Beehive Cluster (Messier 44)

One of the most famous star clusters in the whole sky, the cluster's 'Beehive' nickname comes from the fact that early observers thought it looked like a swarm of bees. It contains over 1,000 stars and is over 600 light years away.

Cigar Galaxy (Messier 82)

Source: Wikipedia Commons © Pablo Carlos Budassi

Deep sky challenge

Spring in the Great Bear

The marginally warmer season is the perfect time to swing your telescope up to point almost overhead and spot some of the treasures hiding within Ursa Major

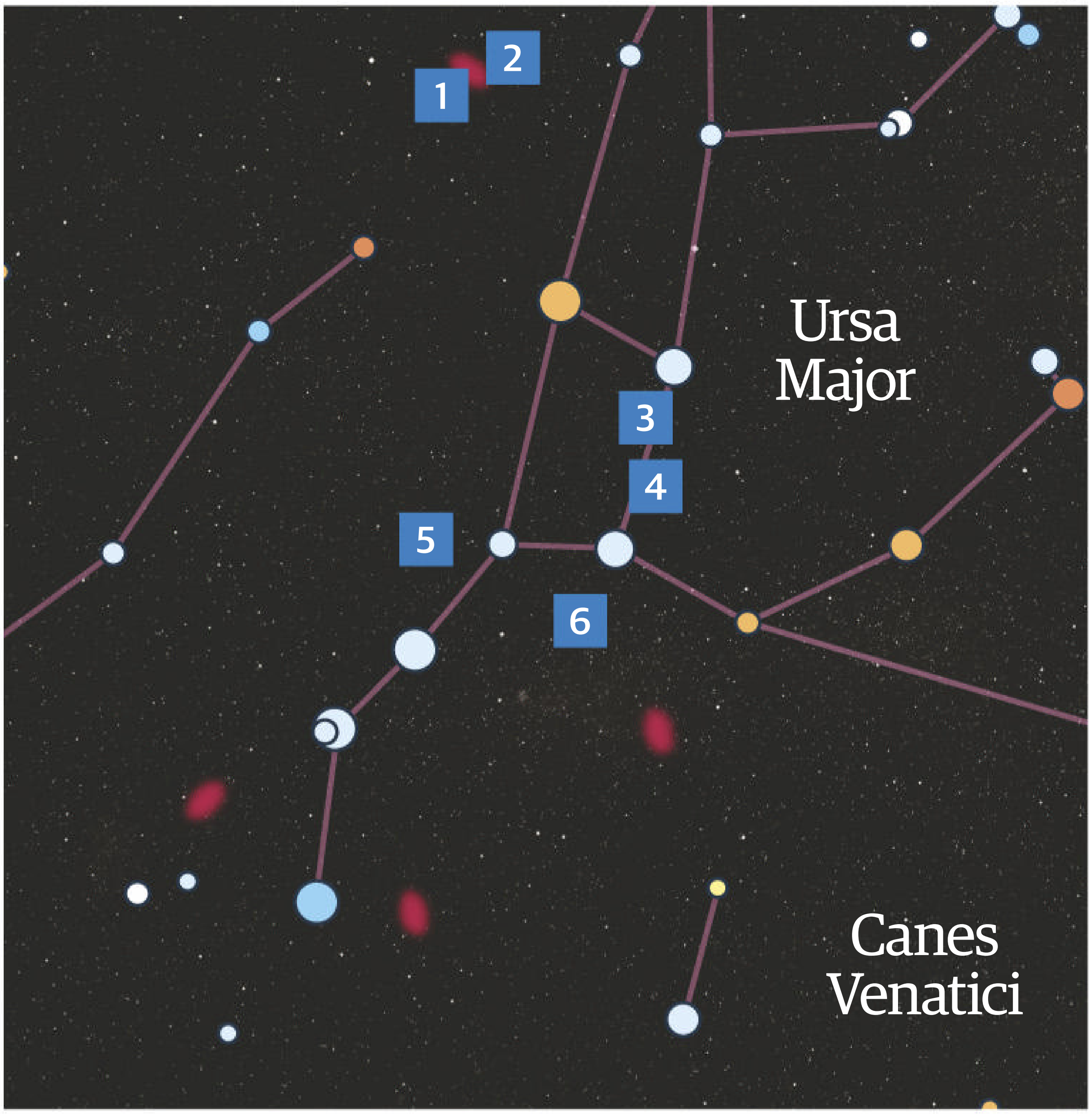
The constellation of Ursa Major is famous for its seven brightest stars, which make up the famous naked-eye asterism the Big Dipper - also known as the Plough - including the close pair of Mizar and Alcor and the twin 'Pointers' that direct the observer in the direction of Polaris, the Pole Star, in nearby Ursa Minor. But behind the stars of this northern constellation, which hangs almost overhead after sunset on these brisk, spring nights, there are some beautiful deep-sky objects for telescope users to enjoy.

Some distance away from the Big Dipper, the close pair of galaxies Messier 81 and Messier 82 are a favourite of many owners of small telescopes, but larger instruments show lovely detailing in the arms and centres of these faraway galaxies. Just beneath the bowl of the Big Dipper, the Owl Nebula (Messier 97) is a very popular target for serious astrophotographers because it really does look like an owl's face in long-exposure photos. Yet like all planetary nebulae - the glowing shells of deceased stars - its appearance in an eyepiece is much more subtle, and you'll only see its resemblance to the face of the wise old bird of prey through a high-power eyepiece in a large telescope.

Owl Nebula (Messier 97)

Source: Wikipedia Commons © Göran Nilsson & The Liverpool Telescope

> "THE CLOSE PAIR OF GALAXIES MESSIER 81 AND MESSIER 82 ARE A FAVOURITE"



1 Bode's Galaxy (Messier 81)

Although this +6.8 spiral galaxy is bright enough to be visible in binoculars as a tiny smudge, larger instruments are needed to show its spiral arms and bright core. It is around 12 million light years away.

2 Cigar Galaxy (Messier 82)

Also known as the Cigar Galaxy, it's much smaller and fainter than its more obvious neighbour, which lies just over half a degree away. On a night of good seeing a large-aperture telescope reveals light and dark patches.

3 Messier 108

Shining at tenth magnitude, this beautiful barred spiral galaxy is visible as an elongated smudge in six-inch telescopes. Instruments of a larger aperture will reveal interesting mottling along its length. It is over 45 million light years away.

4 Owl Nebula (Messier 97)

You'll need at least a medium-aperture telescope to see the two dark 'eyes' of this planetary nebula because of its magnitude and low surface brightness. Through a large telescope you'll see fascinating dappling.

5 Messier's Mistake (Messier 40)

This object is not a galaxy, nebula or cluster, but a close pair of ninth-magnitude stars. It is an optical line-of-sight double rather than a genuine binary star. It is one of the best known anomalies in Messier's famous catalogue.

6 Messier 109

Some 82 million light years away and shining dimly, this barred spiral galaxy is a small, pear-shaped blur through small telescopes. Away from light pollution, telescopes six inches or larger bring out the subtle glow of its curling spiral arms.

Bode's Galaxy (Messier 81)

© NASA, ESA and the Hubble Heritage Team

The Northern Hemisphere

The heavens are alive with galaxies, star clusters and nebulae

The constellations of dark winter skies make way for those famous for welcoming in the warmer spring, so if you're a fan of observing the gems that can be seen in the constellation of Orion, then this month will be your last chance before they disappear from view.

However, don't be too dismayed - Leo (the Lion) and its stunning array of galaxies stands proudly high above the southern horizon as darkness falls. You can find the majestic lion below the base of the Plough, or Big Dipper, which forms part of Ursa Major (the Great Bear). The Leo Triplet, made up of galaxies Messier 66, Messier 65 and NGC 3628, is an easy catch for observers with telescopes of at least small to medium apertures.

Using the sky chart

This chart is for use at 22:00 (BST) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

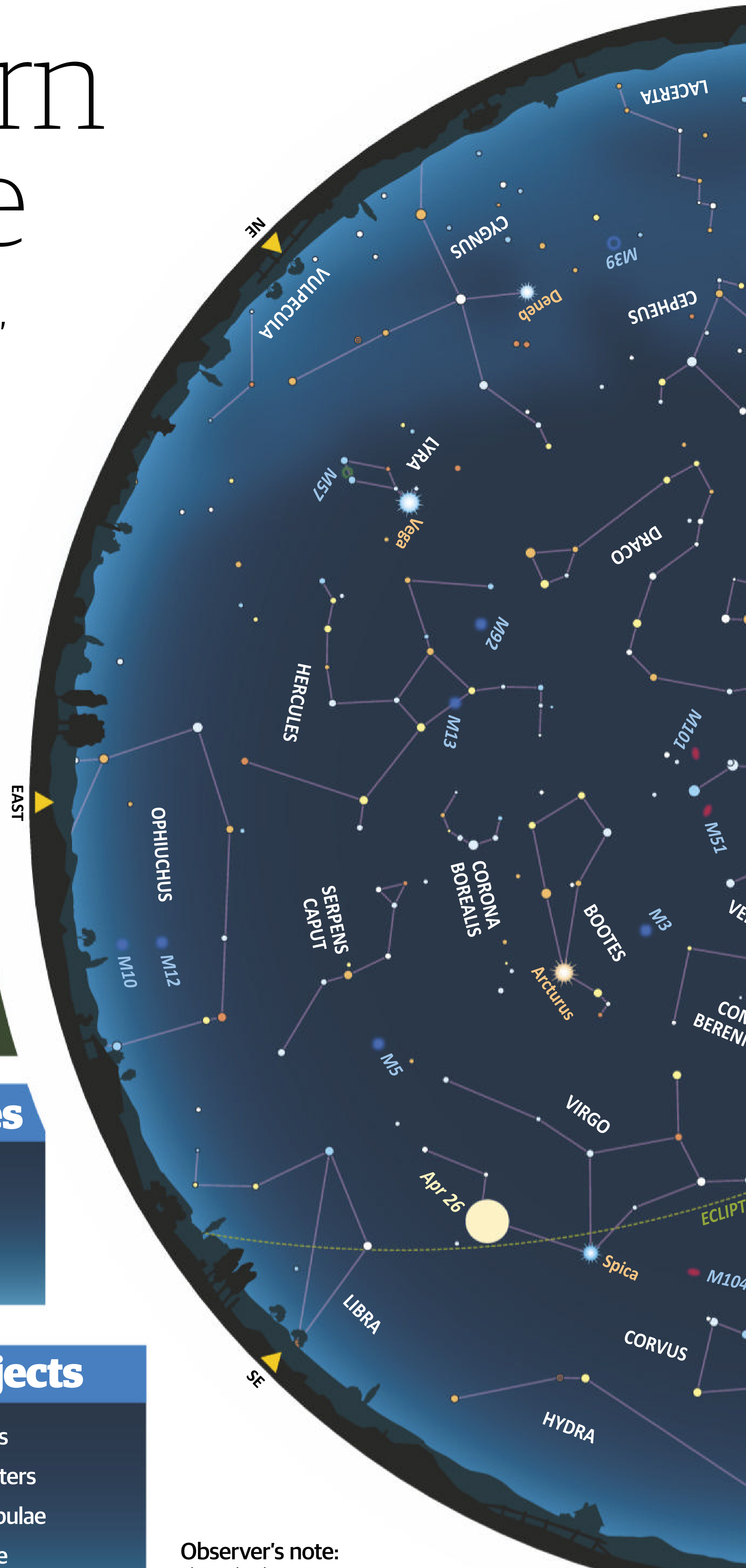
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

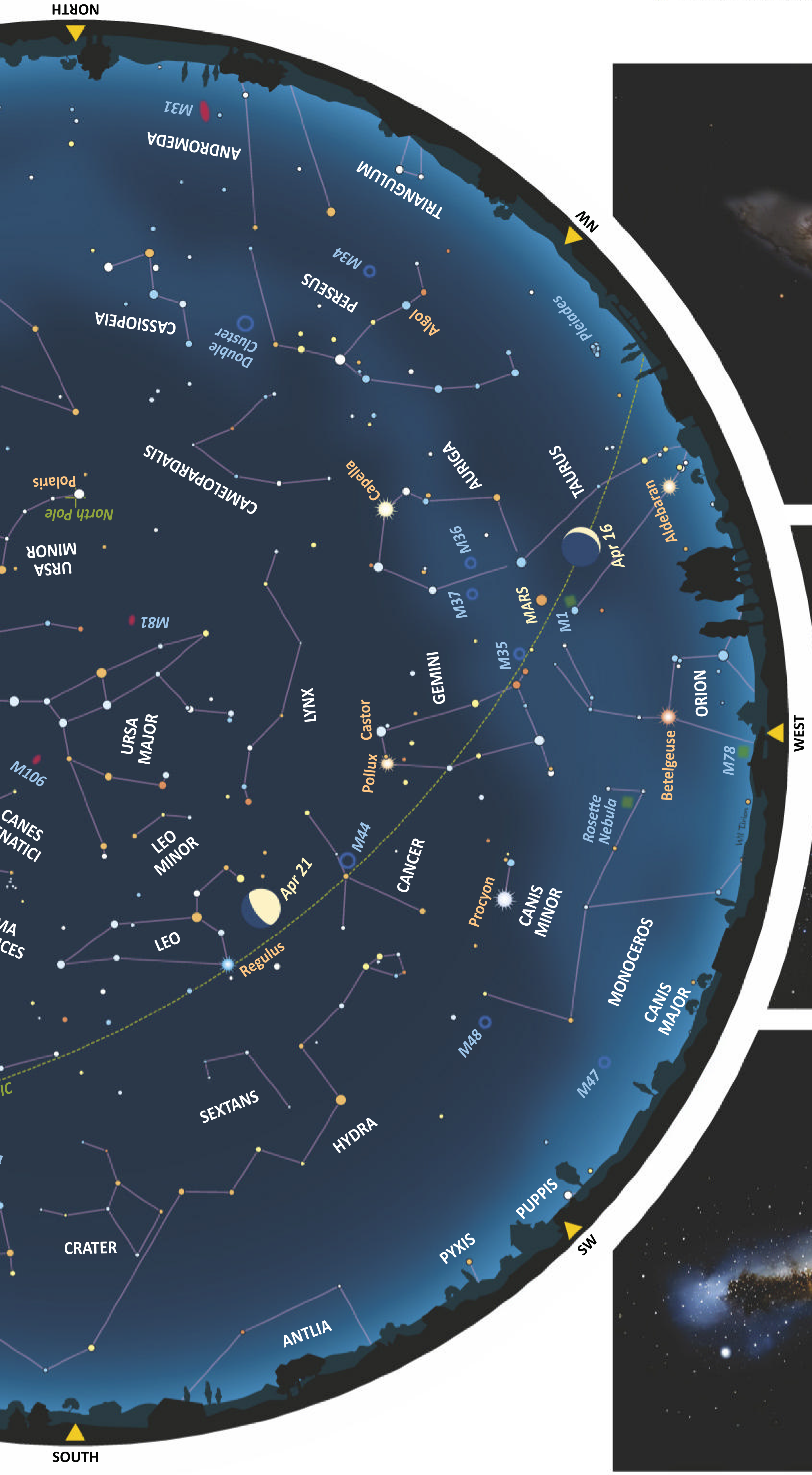
- O-B
- A
- F
- G
- K
- M

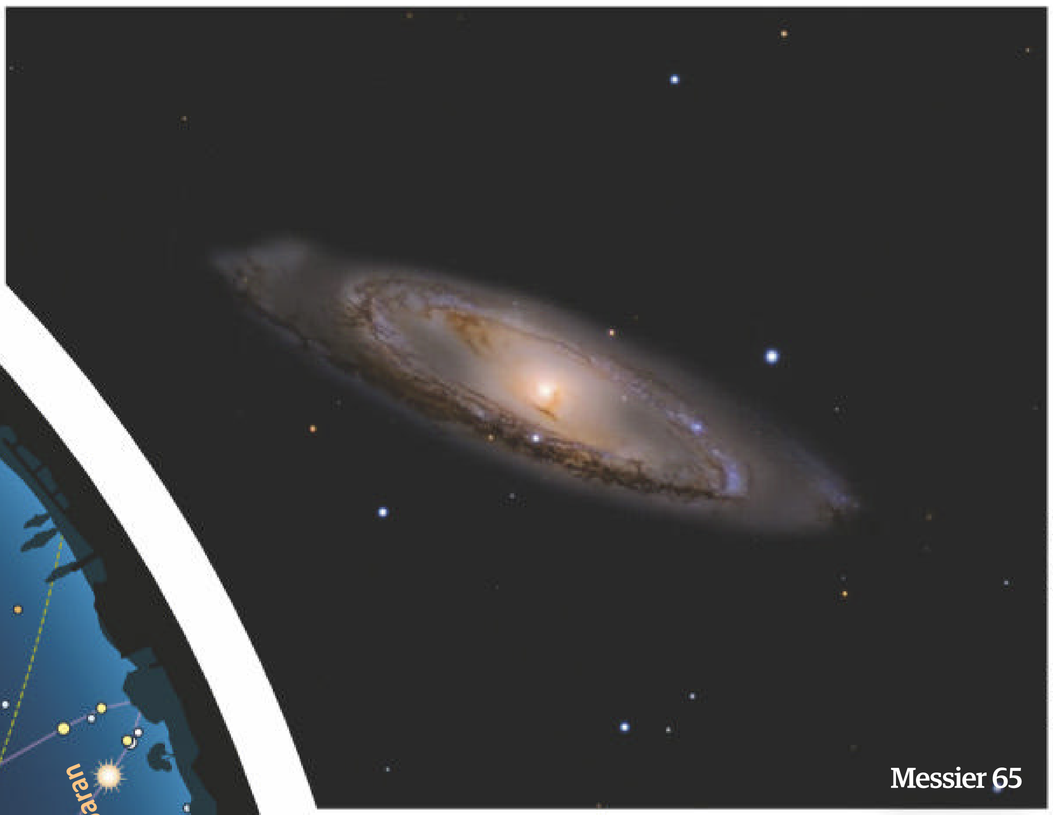
Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies

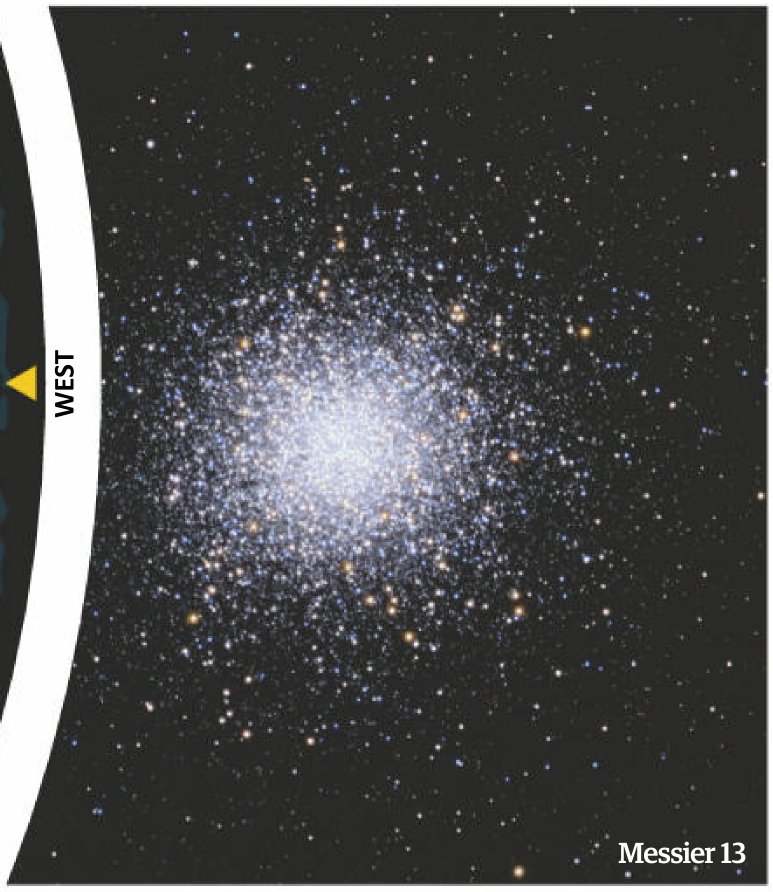


Observer's note:
The night sky as it appears on 17 April 2021 at approximately 22:00 (BST)

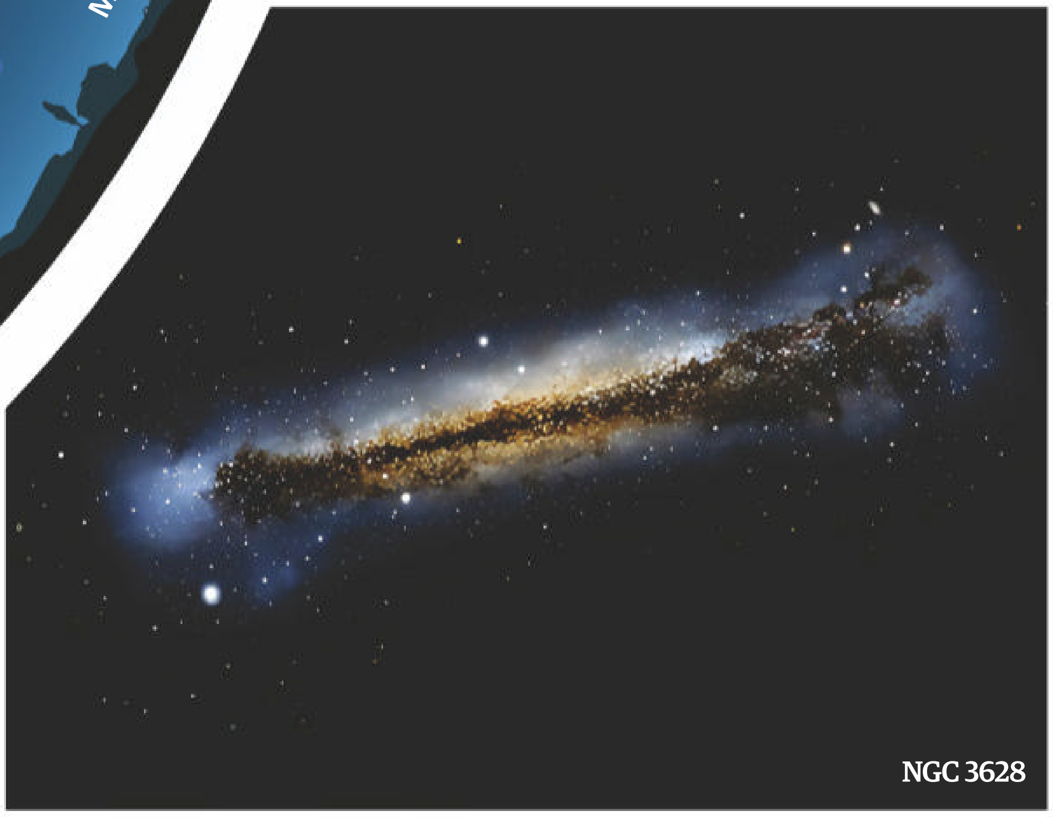



Messier 65

Source: Wikipedia Commons © Ngc1535


Messier 13

Source: Wikipedia Commons © Sid Leach/Adam Block/Mount Lemmon SkyCenter

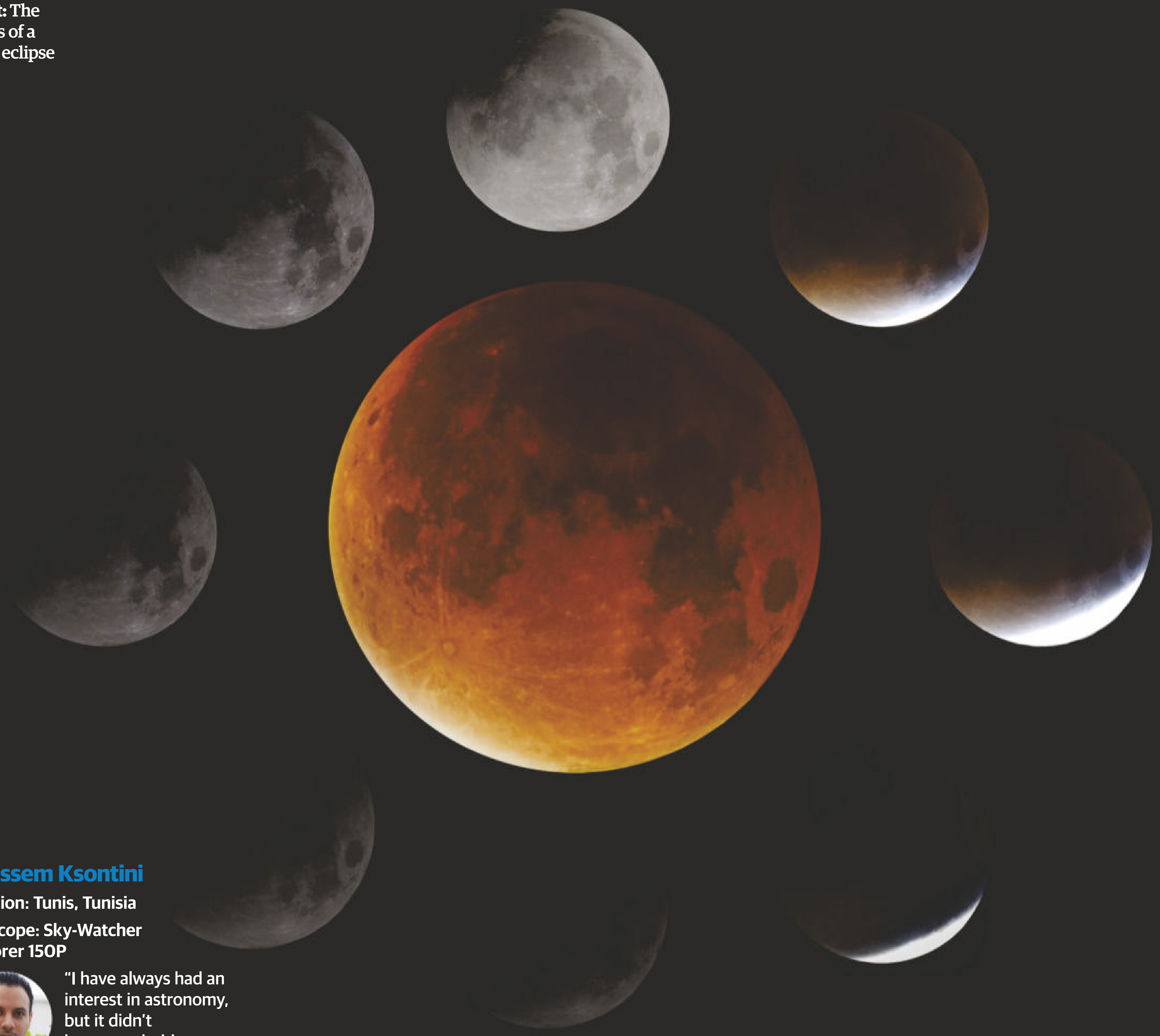

NGC 3628

Source: Wikipedia Commons © Pablo Carlos Budassi

Astroshots of the month

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**

Right: The stages of a lunar eclipse



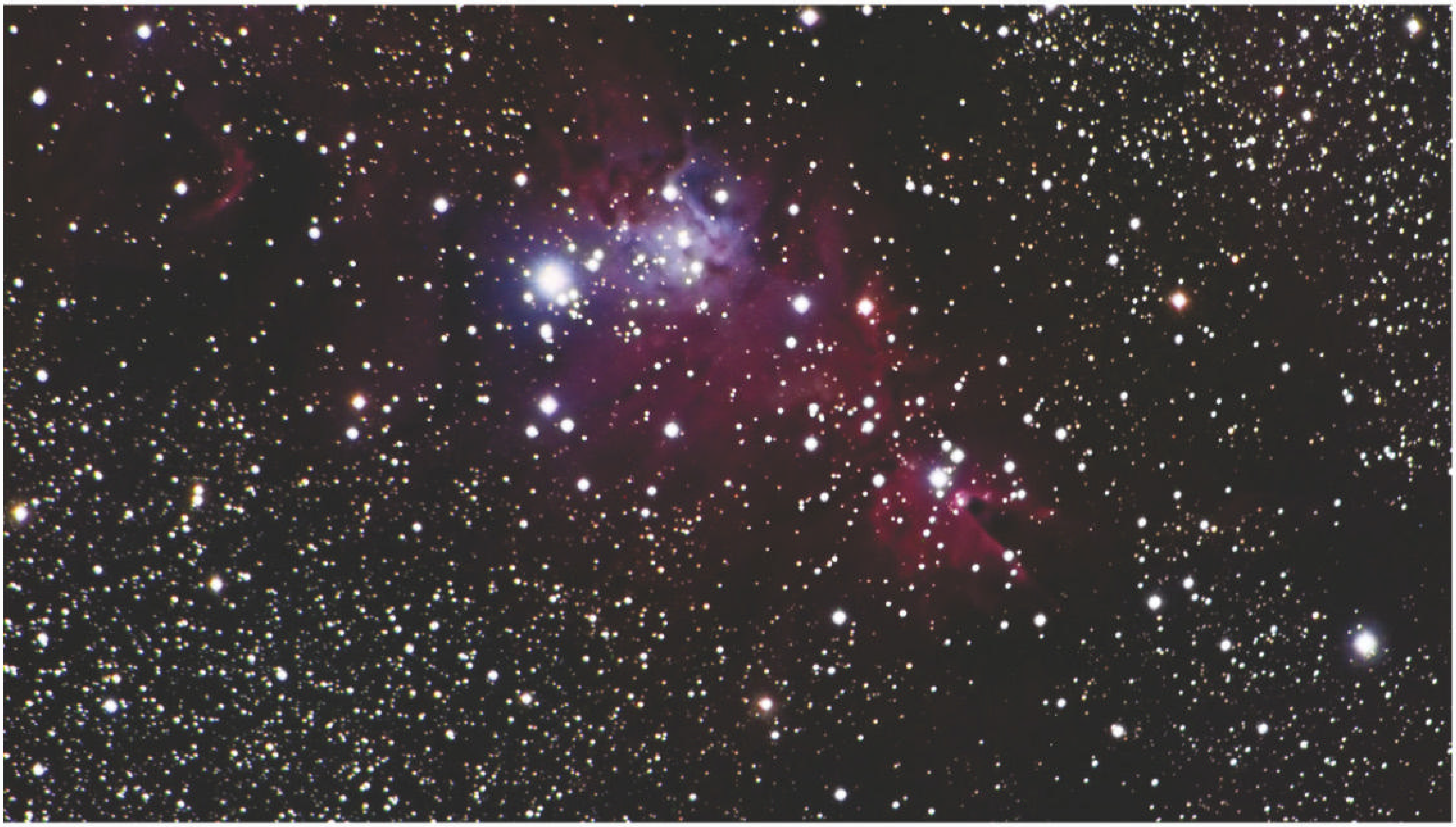
Houssem Ksontini

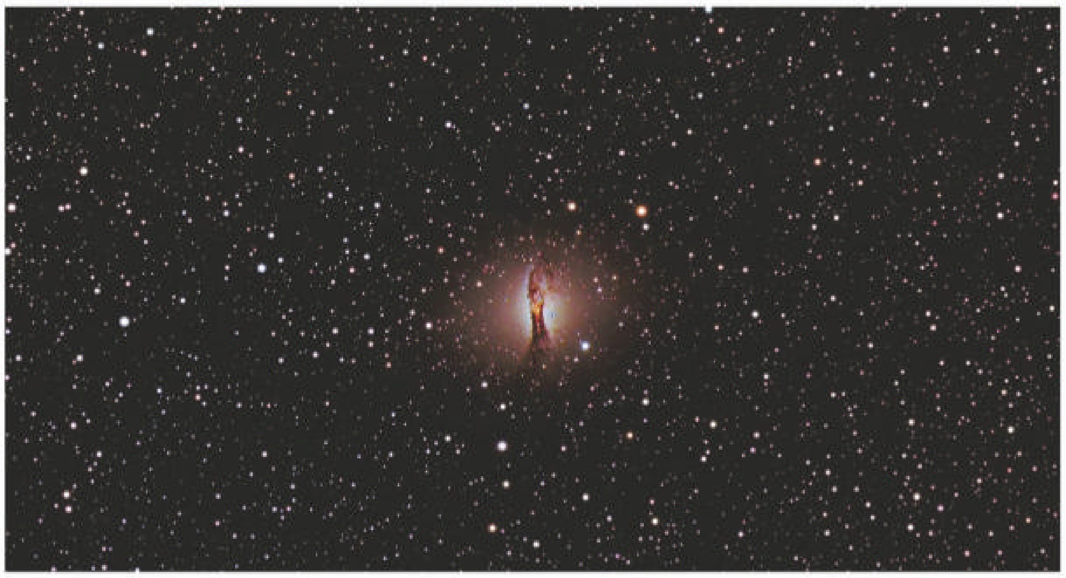
Location: Tunis, Tunisia

Telescope: Sky-Watcher Explorer 150P

"I have always had an interest in astronomy, but it didn't become a hobby until I discovered astrophotography and bought my very first instrument: a Newtonian telescope. While I don't have the benefit of a GoTo mount or autoguiding, I am able to capture the beauty of a variety of deep-sky objects. When I image the Moon and other Solar System targets, I use a modified webcam combined with a Barlow lens for magnified views that afford me stunning views of targets like Mars, Saturn and Jupiter."

> "WHEN I IMAGE THE MOON AND OTHER SOLAR SYSTEM TARGETS, I USE A MODIFIED WEBCAM COMBINED WITH A BARLOW LENS"





Above: The Cone Nebula (NGC 2264)

Left: Centaurus A (Caldwell 77)

Chris Westphal

Location: Florida

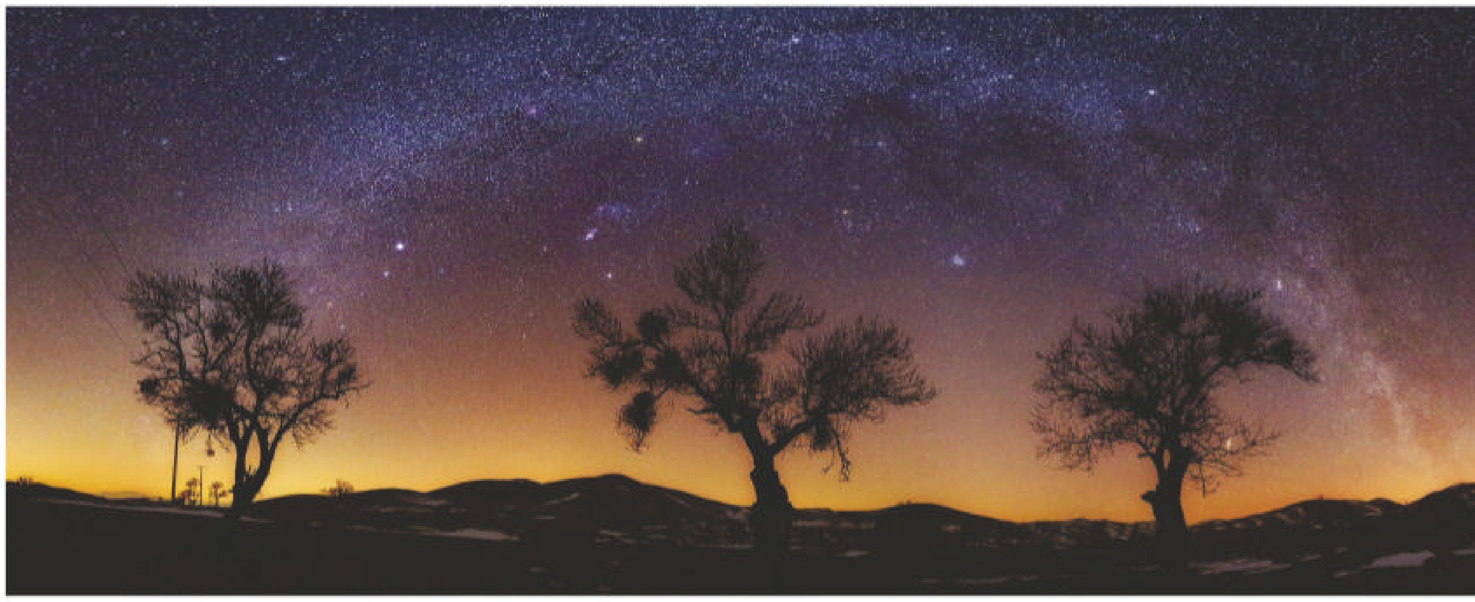
Telescope: Explore Scientific 80mm ED

"From my location in Jacksonville, it's difficult to view or image the Centaurus A Galaxy (Caldwell 77) without a very low horizon. Luckily we have the Winter Star Party in Florida Keys, which allows us to view many southern objects that can often be challenging to observe. During my time at the star party, I used the earlier parts of the night to image the Cone Nebula (NGC 2264) before concentrating on the more difficult southern objects in the small hours of the morning."

Mohammad Mireskandari

Location: Markazi, Iran

"Using my Nikon D7000 camera as well as a Tokina lens, I captured an eight-shot panorama of the Milky Way Galaxy over Iran. As I was imaging our splendid galaxy, there was a cool breeze on my face and the smell of wheat from the nearby fields. At the top of the image, the large spiral galaxy Andromeda can be seen as a small, hazy cloud."



Right: The Milky Way over Iran

Celestron StarSense Explorer DX 130AZ

Clear, crisp views and suitable for the beginner, this reflector also hits the mark for modest budgets

Reviewed by Damian Peach

Telescope advice

Cost: £379.00 / $529.99
From: Celestron
Type: Reflector
Aperture: 5.11"
Focal length: 25.59"

Best for...

- Beginners
- Medium budgets
- Planetary viewing
- Lunar viewing
- Bright deep-sky objects

Choosing a telescope as a beginner is a process often fraught with pitfalls. These days we are spoilt for choice with the enormous range of equipment available. Telescopes for beginners have developed a huge amount over the years. The Celestron StarSense range seeks to truly unveil the wonders of the night sky to those with even the most rudimentary knowledge and experience.

Apertures from 80 up to 130mm are offered in both refractor and Newtonian reflector designs, and all at very affordable price points. Here we review the largest telescope in the range. The DX 130AZ is a 130mm Newtonian reflector telescope. Its focal ratio of f/5 means it is a fast telescope more suited to general lower power viewing of celestial objects. The telescope tube itself attaches to an alt-azimuth mount with dual-axis slow-motion controls.

Both the telescope and mount are nicely made and of good quality. One especially convenient point that we quickly realised is how lightweight and portable the whole system is. One person can easily move around the entire telescope set-up with no problem. Assembly is simple and straightforward following the included instructions.

The telescope itself is moved manually - either by pushing the telescope tube with your hand or using the slow-motion control knobs for fine adjustments. Overall, the whole assembly process took around 15 minutes.

The next step in the process is downloading the StarSense app to your phone. It should be noted that the telescope can be used without a phone and the app - this is not essential, but this is where the telescope really excels for the novice observer.

Being a Newtonian, it's very important to collimate the telescope, and this is quite easy to achieve following the included instructions. We cannot stress enough how important this is if you really want to get the most out of the DX 130AZ - it will make a significant difference to your enjoyment of the telescope.

The telescope comes with two eyepieces, a 25mm and 10mm, giving powers of 26x and 65x respectively, which are suitable for low-power wide-field observing. If you wish to use higher powers, we'd recommend purchasing a good-quality Barlow lens. To see details on the planets you will need magnifications of at least 150x, which is well above what the included eyepieces offer.

Once the telescope is assembled, you're ready to download the StarSense app. The vast majority of popular phones support operation of the app, so it's pretty unlikely you'll come up against a compatibility issue. For the purpose of this review we used a Samsung Galaxy S10+ phone for operation of the app, with no issues encountered.

The StarSense app itself is very easy to use, with an attractive graphical interface and easy-to-understand commands. Once downloaded, you can then dock your phone into the docking station on the telescope, adjusting your phone so its camera is pointing correctly at the docking station mirror. Many different objects are included within the app, such as planets, stars, nebulae and galaxies - enough to keep you busy for a very long time!

Left: The tripod is sturdy, and the mount features dual-axis slow-motion controls

Right: The sleek design of this Newtonian reflector is appealing to the eye

Celestron StarSense Explorer DX 130AZ

Once you are prepared and have a clear night, you are ready to attempt using the telescope under the night sky. We would advise playing around during the daytime to get a feel for everything - it's much easier to resolve initial problems during the daytime than outside in the cold and dark.

Once you're all set up outside, it's time to align the telescope to the night sky. The alignment process is quite clever and straightforward. The StarSense app solves the image it sees from your phone camera to identify where the telescope is pointed, and works quickly and accurately. That advanced alignment technology such as this is now available in beginner telescopes is impressive, and completely takes away the countless hours you would otherwise spend star hopping to different objects - a process that takes far more time and patience! Once everything is aligned, you are ready to start observing objects.

Once set up and aligned, you're ready to begin observing. This is where the DX 130AZ really does impress. Our first target for the telescope was Mars, shining brightly in the southeast. The app instructs you in which direction to move the telescope. As

“A TELESCOPE MORE SUITED TO GENERAL LOWER POWER VIEWING OF OBJECTS”

For

- Great price
- Crisp, clear views
- Superb StarSense app
- User friendly
- Good-sized aperture
- Highly portable

Against

- Undriven mount
- Not suitable for all but the most basic astrophotography
- Supplied eyepieces offer low-power views only

you move by pushing the tube and you draw closer to the object, the app slowly zooms in to allow you to start using the slow-motion controls. Once centred in the bullseye graphic, you are ready to view the target object through the eyepiece. We were impressed to see Mars shining brightly near the centre of the field of view upon glancing in - the telescope passed its first test.

We next decided to move to a variety of different objects, from galaxies to nebulae, all of which were located without issue. Our selected object was always within the low-power field of view. Messier 31, Messier 33, Messier 42, Messier 81 and Messier 82 were all observed, and the views were impressively sharp and contrasty. Afterwards we chose to move back to Mars again and try observing at higher powers using a Barlow lens we had on hand. At around 150x magnification Mars appeared sharp, with the familiar albedo markings visible. Even the tiny south polar cap could be glimpsed. The Moon also showed impressive detail, with a myriad of craters and mountains observed.

Star testing the telescope at higher powers revealed well-corrected optics, and stars focused nicely into tiny, airy discs, as you would expect from a good-quality telescope. It's a shame a higher power eyepiece or Barlow lens isn't included, as for seeing details on the planets you need higher powers than what the included eyepieces offer.

We also decided to try operating the telescope without the StarSense app. The telescope includes a small red-dot finderscope which works really well. It should be noted that it's best to align the finderscope during the daytime on terrestrial objects to save fiddling around in the dark. Even as a simple manual telescope, this set-up works nicely. Of course, using it without the app you have to locate objects 'the hard way', but the motions in moving the telescope are smooth and the slow-motion controls work nicely for centring and keeping objects within the field of view.

While the DX 130AZ is a fine telescope for visual observing, it is not really suited to astrophotography. Since the mount is undriven, long-exposure work is impossible. You can take simple afocal images by holding a phone to the eyepiece, however, and the Moon is a great target for this purpose.

Overall, the DX 130AZ is a nice telescope for the beginner or those just starting out. It would make an ideal gift for a budding young astronomer - we can only imagine how delighted we would have been to have received such a telescope back when we started out! Another great point here is the affordable price tag. You get a very capable system for your money. It's also extremely user friendly, even younger observers would be able to get to grips with it and view some fascinating objects.

No telescope is perfect, however, and this is no exception. It would be good to see a higher power eyepiece or Barlow lens included to allow better views of the planets, essential if you wish to see details on them. Another point worth mentioning is that the telescope must be collimated to perform properly, and collimation isn't the simplest task for the beginner, especially with a Newtonian. That said, its small size makes the process far more rapid than on larger telescopes where you are constantly moving between collimation screws and the eyepiece. The DX 130AZ is a great choice for a first telescope or for those just starting out. Its great user friendliness and capable StarSense app make this telescope an impressively powerful tool that will offer many hours of observing pleasure.

Main: A phone slots comfortably into the mount and doesn't get in the way

Right: The app's interface is user friendly, and will help beginners learn their way around the sky

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ASTRONOMY FOR BEGINNERS

Armed with nothing more than your eyes and a basic grasp of where to look, you can embark on one of the most rewarding hobbies in the world. Many celestial objects can be spotted using only the naked eye. And for those with telescopes, the universe is your personal gallery of a trillion cosmic wonders. Our guides will furnish you with all the essentials, taking you on a journey from stargazing hobbyist to becoming a fully equipped astronomy enthusiast. With practical guidance, seasonal sky charts and pointers on how to spot some of the sky's most accessible sights, this will be your companion as you unravel the beauty of the night sky.

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Inside **MENSA Puzzle Problems**, you'll find a whole host of puzzles that will test your abstract reasoning skills in pattern analysis, visual processing, fluid reasoning, logical deduction and more. As you progress through the book, you'll find that the tests get tougher in order to give you a chance to get used to the types of questions involved, as well as to challenge yourself and improve. All of the answers are provided, but try to resist the lure of the solutions.

BOOK OF MARS

When this first went to press, NASA had just deployed the very first instrument from its InSight mission onto the surface of Mars. InSight is tasked with examining the interior geology of the Red Planet, looking back in time to tell us how Mars, and by extension the other rocky planets - including our own home world - formed. The history of Mars is intrinsically bound up with that of Earth - some scientists even think that the original building blocks of life came from there. Here we'll reveal what scientists know about the planet, examine the theories that may help us understand it further and explore how we could make it into another human home.

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In the shops

The latest books, apps, software, tech and accessories for space and astronomy fans alike

1

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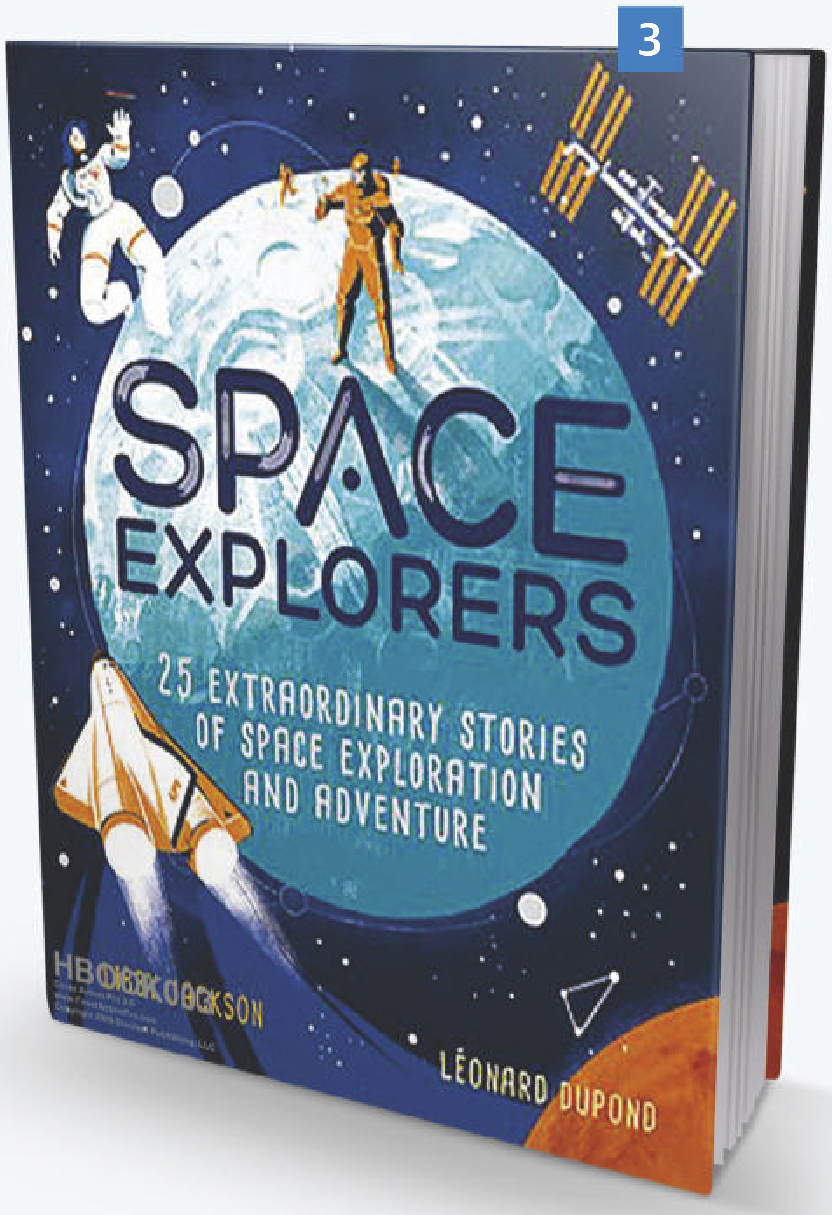


1. For fun

LEGO International Space Station

Cost: £64.99 / $69.99

From: lego.com

Build your very own International Space Station with this striking 864-piece LEGO kit. Don't be put off by this challenging build, as the kit also comes with a 128-page building instruction booklet to guide you through the construction process. Once assembled, this incredible ISS kit can be mounted on the included display stand. Designed by LEGO fan Christoph Ruge, who is passionate about space, this ISS design was championed by the fan community and selected as the ideal set to celebrate the tenth anniversary of LEGO ideas.

2. For astronomy

Astrozap Flexible Dew Shield

Cost: From £21 (approx. $29.30)

From: firstlightoptics.com

Defend your night-sky viewing experience against pesky dew formation with this lightweight dew shield from Astrozap. Available in a range of sizes for all kinds of telescopes, this product is designed to achieve a snug fit for optimal protection. Made from durable ABS plastic with a felt-lined interior and Velcro fasteners, the shield comes with a two-year guarantee for peace of mind. The design also allows for easy storage by either rolling the shield up or laying it flat. It's a must-have accessory this astronomy season.

3. For bookworms

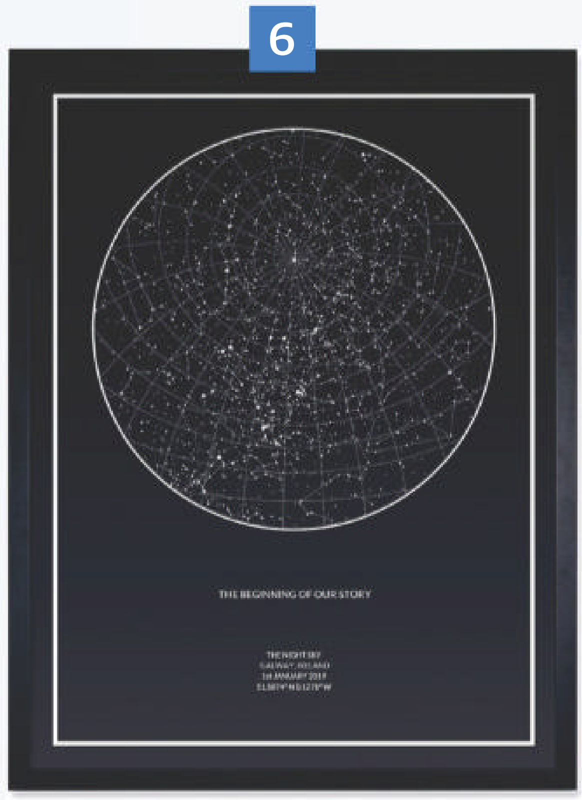
Space Explorers: 25 Extraordinary Stories of Space Exploration and Adventure

Cost: Paperback £9.99 (approx. $13.95)
Hardback £14.99 (approx. $20.90)

From: Waterstones

This beautifully illustrated book is a collection of amazing real-life stories about space exploration and adventure. Written by Libby Jackson, human exploration program manager at the UK Space Agency, and illustrated by the talented Leonard Dupond, this is a terrific gift for curious minds. Let your children's imagination run wild with this insightful and fun book that is guaranteed to take them on an astronomical adventure.

"THE PROJECTIONS ARE MASTERFULLY CREATED USING DATA FROM NASA, THE NOAA AND USNO"



4. For your desk

Science Museum Planet Sticky Notes

Cost: £5.00 (approx. $6.90)
From: Science Museum
Liven up your home, study or work space and never forget something important again with these quirky Science Museum Planet Sticky Notes - much more interesting to look at than the standard yellow squares! These easy-peel planets come in four unique designs and can stick onto refrigerators, desk surfaces and even walls. The paper notes measure 7.5 by 7.5 by 0.6 centimetres (2.9 by 2.9 by 0.2 inches), and with 60 planets in a pack, there are plenty of opportunities to sit back and take note of the world around you.

5. For indoor observing

Sega Homestar Flux

Cost: £169 (approx. $234.91)
From: segatoys.space
This powerful star projector can project onto a ceiling, wall or any other flat surface at a distance of 120 to 290 centimetres (47 to 114 inches). Two discs of the Northern Hemisphere are included, both with and without constellation lines. You can purchase additional discs which include the Andromeda Galaxy and Southern Hemisphere, as well as stunning images of Earth and the Moon. The projections are masterfully created using data from various NASA, the National Oceanic and Atmospheric Administration (NOAA) and the United States Naval Observatory (USNO).

6. For your home

Your Night Sky Custom Starmap

Cost: from £40 (approx. $55.80)
From: thenightsky.co.uk
Celebrate that special moment and give the gift of the stars with this custom star map. The simple interface allows you to effortlessly choose a date, time and location for your night sky print. You can further customise your map with additional options regarding constellations and background colours, including black, white and midnight blue. Once you have created your star map you can then have it printed and posted with or without a frame or onto a canvas of varying sizes and orientation. With plenty of ways to make this truly your own, the custom star map makes for a perfectly unique gift.

Christopher C. Kraft Jr.

NASA's first flight director, Kraft established Mission Control as we know it today

Kraft has been hailed as the father of NASA's Mission Control Center, and was a core team member in the quest to put humans on the Moon. Joining the NASA Space Task Group in 1958, Kraft became NASA's first flight director and established the concept of NASA's Mission Control, laying the foundations for its operational procedures and culture. Kraft always had to be one step ahead, trying to solve problems before they even arose. His responsibilities spanned a wide range of areas, from go/no-go decisions, space-to-ground communications and space tracking, as well as crew recovery.

His level-headed and strategic approach to manned missions resulted in him becoming deputy director of the Manned Space Center - now the Johnson Space Center - in 1969. Here he worked on Apollo 12, and he also played a critical role in bringing the ill-fated Apollo 13 back to Earth safely. In 1972 Kraft was promoted to director, and he was a key component in the success of the final Apollo missions, Skylab, the Apollo-Soyuz Test Project and the first flights of the Space Shuttle until his retirement in 1982.

After retiring, Kraft refused to sit back and take it easy. He consulted for various organisations, including IBM and Rockwell International. Kraft also served two terms as director-at-large of the Houston Chamber of Commerce and two four-year terms as a member of the board of visitors at Virginia Tech. Despite his busy schedule, Kraft still found time to write an autobiography entitled *Flight: My Life in Mission Control*.

Kraft received numerous awards and honours during his lifetime, with two of the most significant coming from NASA itself. In 2006 NASA honoured Kraft for his fundamentally important role in America's space programs with the Ambassador of Exploration Award. Additionally, in 2011 NASA's Building 30 Mission Control Center at the Johnson Space Center was renamed, and is now known as the Christopher C. Kraft Jr. Mission Control Center.

Despite many awe-inspiring accomplishments throughout his career, Kraft's journey into aeronautics was not preordained. Firstly, he had absolutely no interest in aeroplanes before he got to college. Born 28 February 1924 in Phoebus, Virginia, now part of Hampton, Kraft's passions at high school were baseball and drum-and-bugle corps. After high school he enrolled to study mechanical engineering at Virginia Polytechnic Institute, and also became president of the Corps of Cadets. Kraft later credited his experience in the military Corps of Cadets at the Institute for shaping the personality that made him so successful in his NASA career. During his time at college, Kraft became inspired by a professor in his engineering department, who passed on his enthusiasm for aviation. He then decided to major in aeronautical engineering. In 1944 Kraft graduated with one of the first degrees in that field awarded by the institute.

Kraft was one of the men behind Apollo, ensuring the success and safety of the missions and astronauts

© NASA

After college Kraft had planned to join the Navy, but due to an accident when he was three years old which left his right hand severely burnt, he was deemed unfit for military service. In 1945 Kraft joined the Langley Aeronautical Laboratory of the National Advisory Committee for Aeronautics (NACA). Before joining NASA, Kraft had already significantly contributed to aeronautical flight research, investigating aircraft design problems in the stability and control branch at NACA. He married his high-school sweetheart Betty Anne Turnbull in 1950, and they had two children, Gordon and Kristi-Anne.

Sadly, Christopher C. Kraft Jr. passed away on 22 July 2019 at the old age of 95. The director of NASA's Johnson Space Center, Mark S. Geyer, warmly remembers him as "a visionary, an American hero and a great leader".

All About Space

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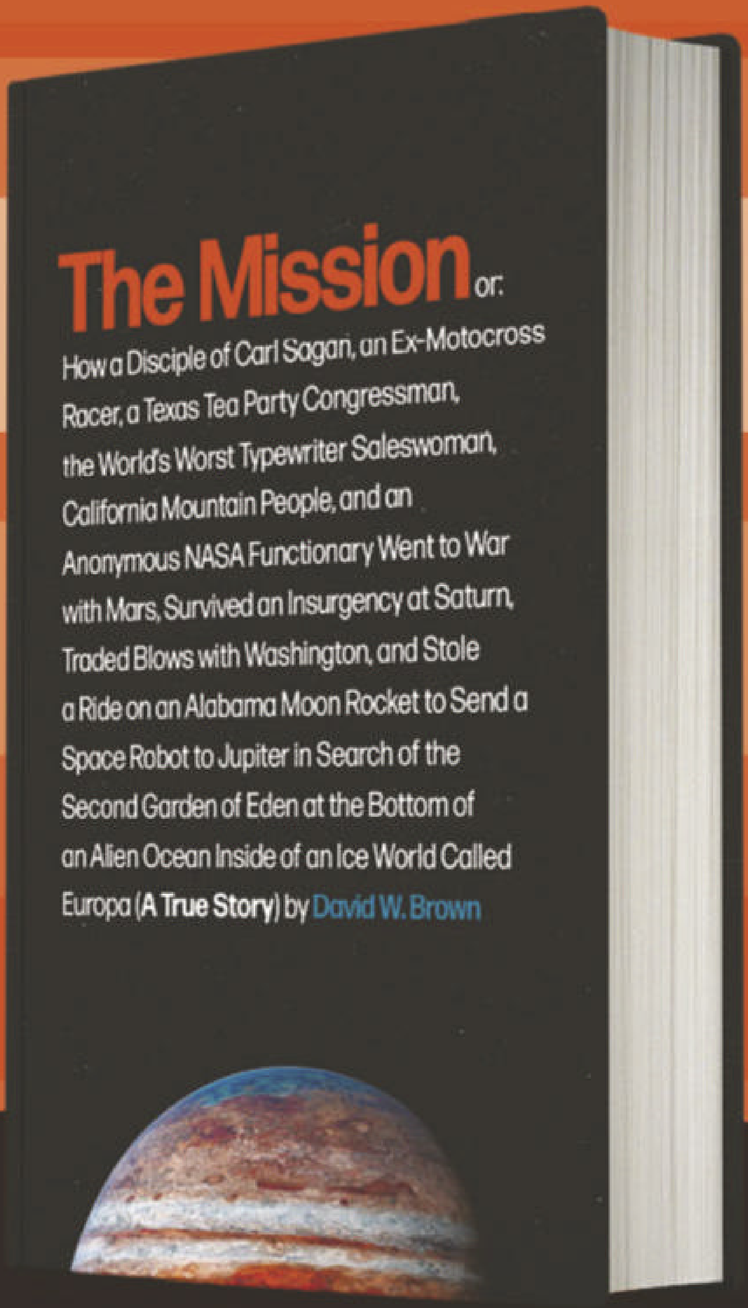
The Mission

A TRUE STORY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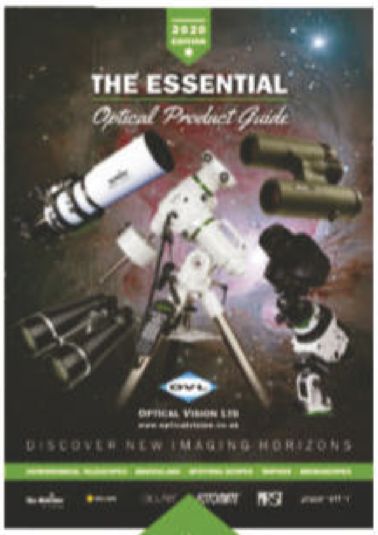
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